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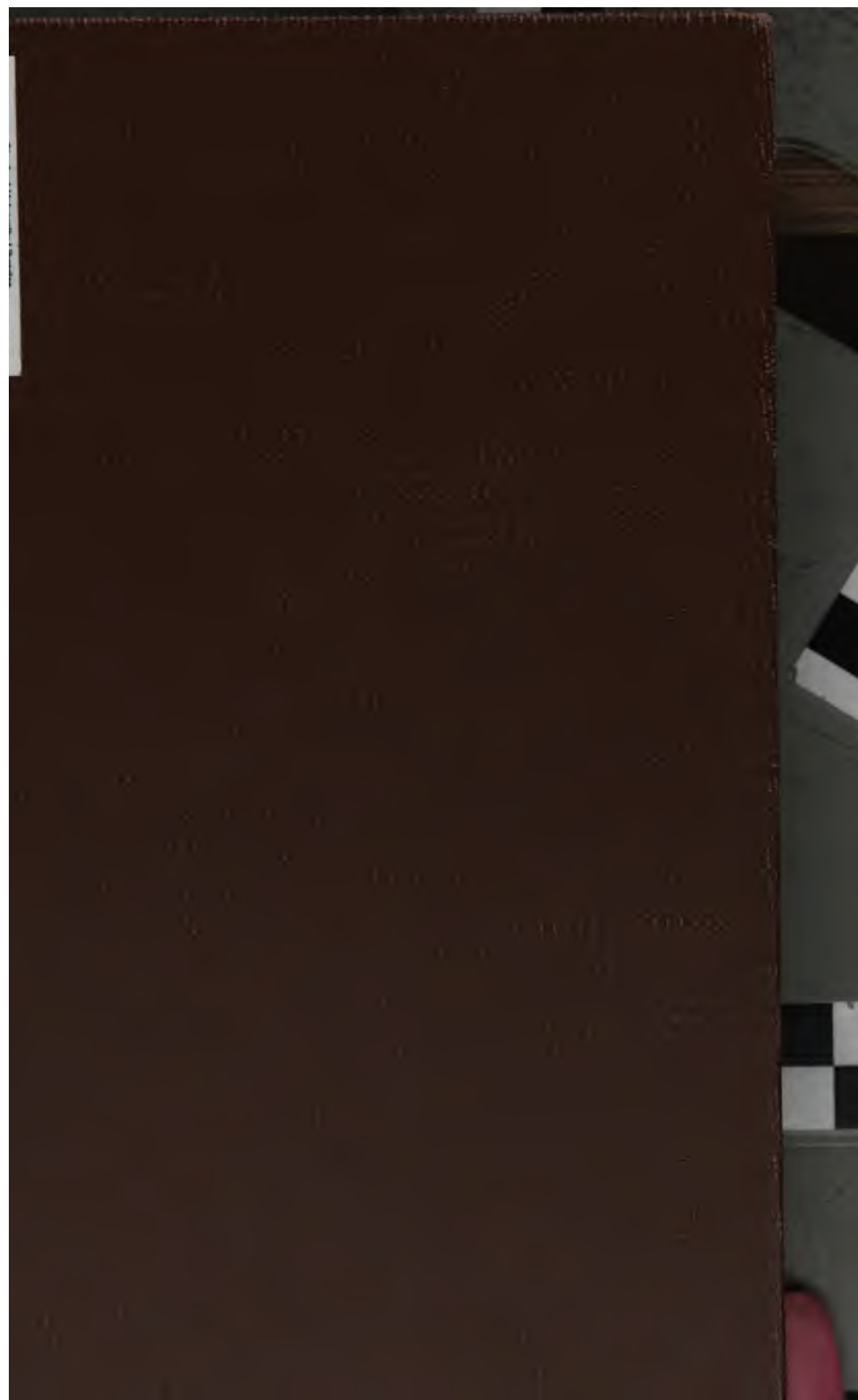
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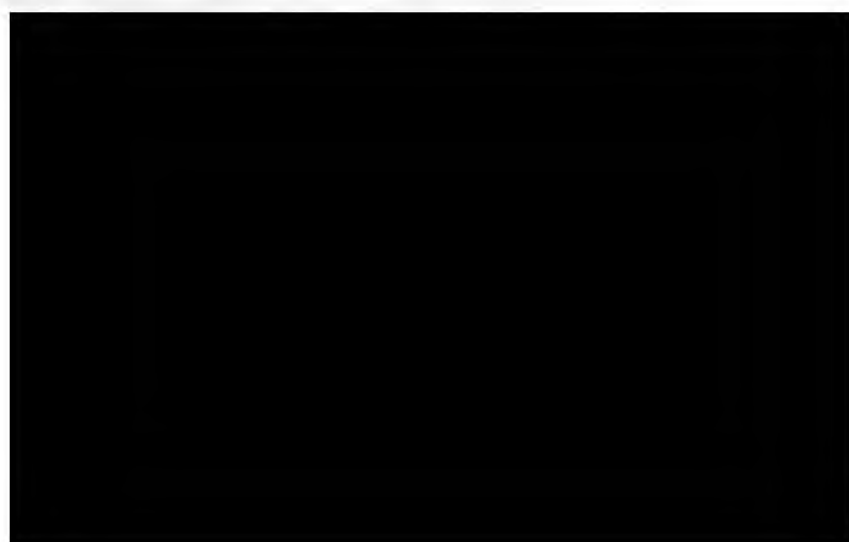
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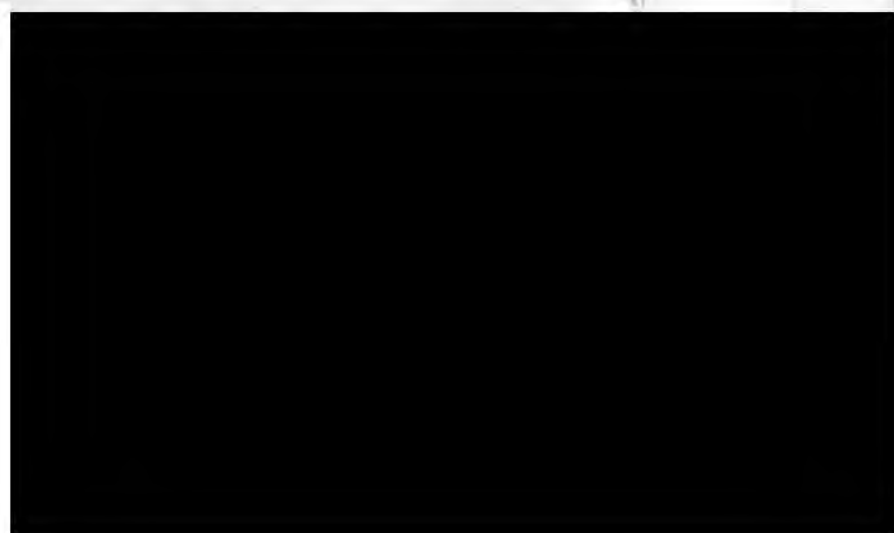
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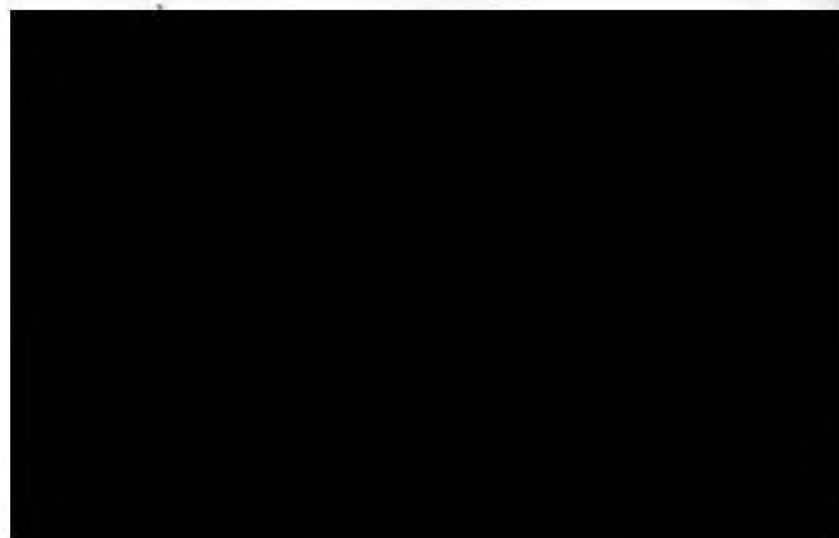
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGY AND OIL RESOURCES
OF THE
SANTA MARIA OIL DISTRICT
SANTA BARBARA COUNTY
CALIFORNIA

BY
RALPH ARNOLD AND ROBERT ANDERSON



WASHINGTON
GOVERNMENT PRINTING OFFICE
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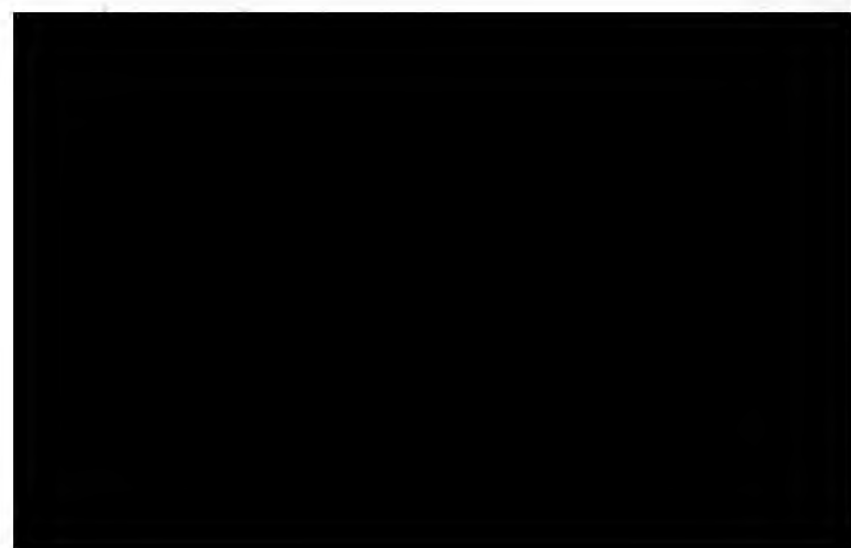
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GEOLOGY AND OIL RESOURCES OF THE SANTA MARIA OIL DISTRICT, SANTA BARBARA COUNTY, CAL.

By RALPH ARNOLD and ROBERT ANDERSON.

INTRODUCTION.

PURPOSE OF THIS REPORT.

During the last three years the region near the Pacific coast in the northern part of Santa Barbara County, Cal., has shown promise of becoming one of the most productive oil fields of the West, if not of the whole United States. The developed fields lie on the low, rolling hills between the Santa Maria and Lompoc valleys, where the oil has accumulated in great abundance in the Monterey shale, of middle Tertiary age, which underlies this region. The lightness of the oil, which averages from 25° to 27° Baumé, and the great productiveness of the wells, which yield as high as 3,000 barrels a day, with an average of 300 to 400 barrels, are among the features for which the district has become noted. Large areas in the same general region as the productive fields have been known for some time to be analogous, so far as surface evidence went, to the proved territory, and it was thought that geologic investigations of the region might furnish valuable information and aid in the extension of developments. Accordingly, with the purpose of studying the occurrence of the oil, the extent and structure of the oil-bearing formations, and their relations to associated formations, the writers carried on the field work leading to the present report during the summer and autumn of 1906. The geology of the region covered by the accompanying geologic map (Pl. I, in pocket) has not been completely studied in all parts. Between the San Rafael and Santa Ynez ranges it has been worked with considerable detail, but the mapping of the mountainous regions has been more in the nature of a reconnaissance outside of the areas of the Monterey formation.

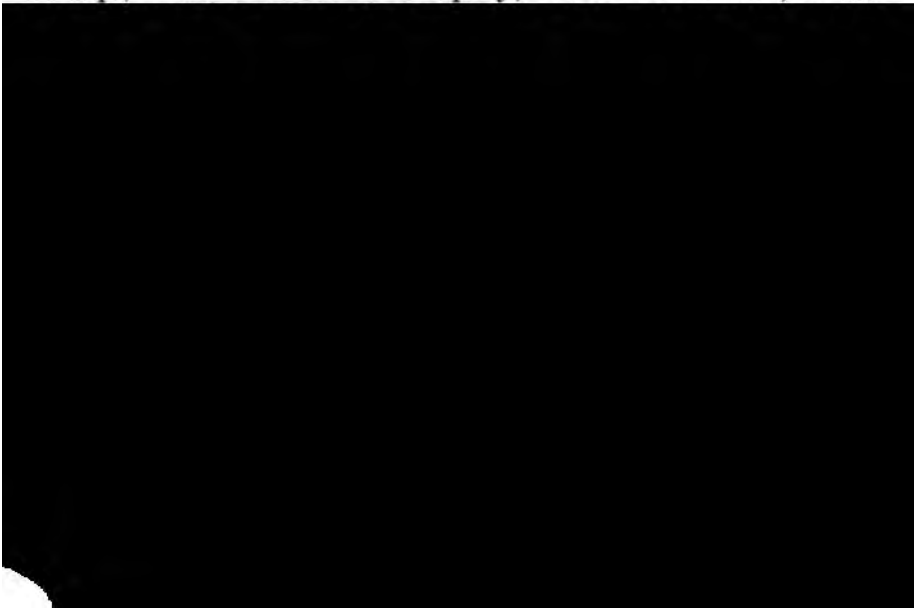
A preliminary paper containing the features of this report most immediately pertinent to the oil developments and an outline map has been published as Bulletin No. 317 of the United States Geological Survey.

ACKNOWLEDGMENTS.

Mr. H. R. Johnson covered the territory northeast of the Santa Maria Valley, and the map and notes concerning that region are largely the result of his work. Dr. H. W. Fairbanks^a is quoted on the geology of Point Sal.

The writers are greatly indebted to Mr. F. J. Keeley and Prof. C. S. Boyer, of Philadelphia, and to Dr. Albert Mann, of the United States Department of Agriculture, for information concerning diatoms and their relation to the origin of the oil. Acknowledgments are also due to Messrs. E. C. Sullivan, W. T. Schaller, and George Steiger for making analyses of the Monterey shale. The analyses of oil on pages 115-117 were made by H. N. Cooper and published by the California State Mining Bureau in its Bulletins Nos. 31 and 32. The indebtedness of the writers to Mr. Cooper and to the mining bureau for this information is hereby acknowledged.

Without the assistance of the operators in the developed field that part of the report which relates to the geology of the wells, production, and other technical data would have been an impossibility, and the writers therefore wish to acknowledge their indebtedness to the officers and managers of the different oil companies for their hearty cooperation and support. Thanks are due more particularly to Mr. W. W. Orcutt, geologist of the Union Oil Company; Messrs. J. F. Goodwin and F. J. Burns, of the Pinal and Brookshire oil companies; Judge John D. Bicknell and Mr. Morris Albee, president and secretary, respectively, of the Western Union Oil Company; Mr. Adolph Phillips, of the Graciosa Oil Company; Mr. W. O. Maxwell, of the



in the early fifties.^a In the report on this work the larger topographic features were well described, the presence of asphaltic rocks was briefly noted, and the Tertiary age of most of the sedimentary rocks was recognized, but the structural features and the relations of the rocks were in the main misinterpreted.

During the course of the geological survey of California by J. D. Whitney a hasty reconnaissance was made of a part of this region.^b He says in his report:

The region to the west of the San Rafael Range, between the Santa Ynez and Cuyamas rivers, was cursorily examined by our party. * * * The region is occupied by hills of moderate height. No metamorphic rock was seen; but pebbles of serpentine and metamorphic sandstone were noticed, especially for 3 or 4 miles north of Alamo Pintado. * * * These hills were covered with gravel derived from the bituminous slates. At times, especially near the Santa Maria River, the hills were capped by a modern horizontal deposit (post-Pliocene?). The underlying rock, when seen, was the bituminous slate, sometimes dipping to the north and sometimes to the south.

Near Foxen's, on the south side of the valley, there were hills of nearly horizontal strata from 200 to 300 feet high, the north slopes of which were very steep, usually about 35°. Beneath the soft sandstone, which made up the principal part of these hills, was a stratum of infusorial rock resembling chalk in appearance, exceedingly light, its specific gravity not being more than 0.6 or 0.7; the thickness of this stratum was over 20 feet. The age of this formation is not yet definitely ascertained.

North of the valley, at Foxen's, the bituminous slate occurs with a high dip to the north, and asphaltum is found in several localities near. In places the slates are altered and silicified, sometimes resembling semiopal in appearance, the finest laminae of the original structure being preserved.

So far as the writers are aware no further investigation of the geology of the region was made until H. W. Fairbanks made examinations of portions of the Coast Ranges and reported on them for the State mining bureau in 1894. In his paper on the "Geology of northern Ventura, Santa Barbara, San Luis Obispo, Monterey, and San Benito counties" reference is made^c to the region under discussion, especially to the Santa Ynez Mountains. Regarding the Santa Ynez Range he says: "It is formed, so far as is known, of Miocene rocks exclusively." And again:

There can be no doubt that the main portion of the Santa Ynez Range is Miocene with a general anticlinal structure, well shown in the San Marcos Pass. The center of the anticlinal is not generally the highest portion of the range, but lies on the eastern slope. The normal type of anticlinal structure is also marked by an east and west compression, producing features, however, of secondary importance.

As viewed from the south at various points the range consists of heavy-bedded sandstone, dipping at a high angle to the south. * * * At the western end, in the vicinity of Point Arguello, no anticlinal structure is apparent, but steeply inclined and broken strata. Asphaltum is found in many places near the sea from Point Arguello to Ventura County.

^a Pacific R. R. Repts., vol. 7, 1857, Chaps. VIII, IX, and X.

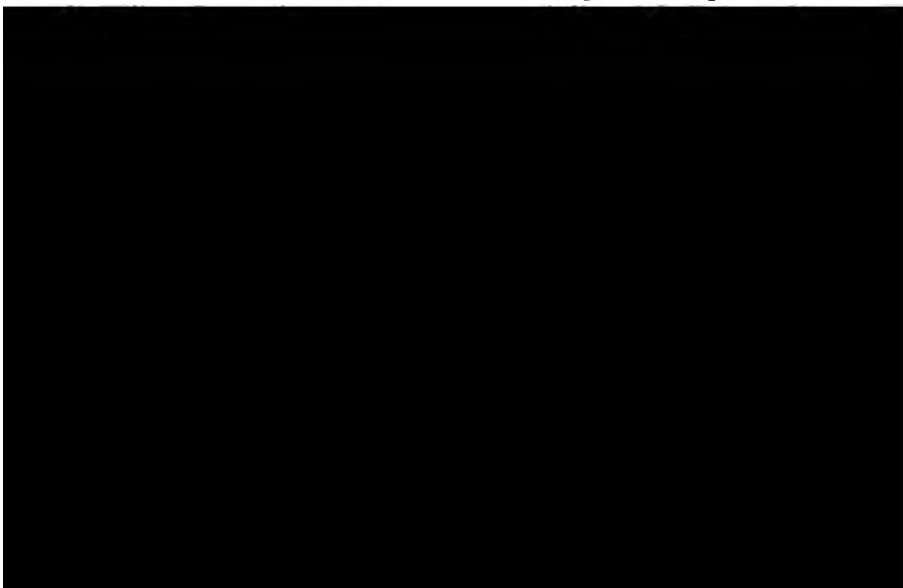
^b Geological Survey of California, Geology, vol. 1, 1865, pp. 135-138.

^c Twelfth Ann. Rept. California State Mining Bureau, 1894, pp. 498-506.

The present writers are in agreement with these statements except as regards the exclusively Miocene age of the rocks, a large part of which are here considered as Eocene. On page 505 of Fairbanks's article he speaks of "shales and sandstones of undoubted Cretaceous age" between Gaviota Pass and Santa Ynez River, in the hills which in the present paper are considered as part of the Santa Ynez Range. In the very short time spent in this locality the present writers found no evidence of the presence of Cretaceous rocks.

A number of asphalt deposits in northern Santa Barbara County are described on pages 30 to 33 of the twelfth annual report of the State mineralogist, cited above. The localities mentioned are on the Los Alamos grant, 4½ miles north of Harris station; along the northern slope of the hills bordering the Santa Maria Valley, 10 miles southeast of Santa Maria; about 2 miles northeast of the Purisima Mission; along the southern slope of the hills between the Los Alamos and Santa Ynez valleys (Purisima Hills), especially on the San Carlos de Jonata grant; and in poorer and less known deposits at Gaviota Landing, at Point Arguello, near the mouth of Canada Honda, and at other points toward Lompoc Landing. Seepages out of the bituminous "slate" (shale) series are mentioned as occurring in the canyon of the Sisquoc, about in the center of the Sisquoc grant, along Labrea Creek, and near the west end of the Tinaquaic grant.

By far the best observations recorded up to 1896 regarding the geology of this region were those of H. W. Fairbanks, published in his paper on the "Geology of Point Sal."^a He gives a detailed description of the igneous and sedimentary formations occurring at the seaward end of the hills, termed in the present report the Cas-



divisible into two distinct parts—the upper, the bituminous shales, and the lower, the gypseiferous clays. Below the clays are sandstone, shales, and conglomerates resting on the gabbro and serpentine. * * * The strata of volcanic ash appear in the lower Miocene beds. There are three distinct horizons, the lowest resting on the gabbro.

The igneous rocks are treated in especial detail in this paper and a very good description is given of the bituminous shales. The conclusions of the present writers are in agreement with the statements above quoted and the others contained in Fairbanks's paper.

In 1901 George H. Eldridge gave an admirable general outline of the topography and geology of the country surrounding the Santa Maria field in his treatise on "The asphalt and bituminous-rock deposits of the United States," and discussed in detail its asphalt deposits.^a He says:

The geology of the region embraces an underlying series of folded Monterey shale of both the soft and more organic material and that which is hard and siliceous, but the former predominates. So far as observed by the writer this series of beds was not exposed at any point in its entirety. Overlying the Monterey unconformably, and especially developed in La Graciosa Hills, is the heavy and extensive deposit of Pliocene sands, grits, and conglomerate already referred to. The composition of the later deposit is chiefly quartzose.

Eldridge "observed a prevailing central fold somewhat to the north of the topographic axis of the ridge" south of Waldorf, in the Casamalia Hills, this being no doubt the fold described in the present report as the Schumann anticline. He says further:

The Pliocene * * * shows a less degree of folding than the underlying Monterey, yet the movement that produced the pre-Pliocene ridge has apparently been continued subsequent to the deposition of the materials of this age, for gentle dips of from 2° to 10° are to be observed in the later formation.

In discussing the country east of Los Alamos, between the San Rafael Range and the Santa Ynez Valley, which he calls the Los Alamos region, Eldridge says:

In structure the Los Alamos region presents a series of folds which are in general coincident with the topographic ridges and valleys. * * * It is worthy of note that the valleys of the region under consideration for the most part occupy the synclinal troughs. It is possible that some of them also occupy fault lines. * * * The general trend of the folds for the Los Alamos district, and indeed for a great stretch of country beyond, is N. 70° to 80° W., the dips being north and south. Excepting in their trend, however, there is but little regularity in the disposition of the folds, and their axes, both longitudinal and transverse, vary greatly in length. In addition to the main and conspicuous folding that has been described, there are frequent crumples of minor importance.

In another place Eldridge mentions a lens of limestone included in the serpentine in a high bluff just north of Alamo Pintado Creek, along the old beach line where the Fernando was deposited upon the Franciscan at the base of the San Rafael Mountains. This lime-

^a Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 1, 1901, pp. 424-441.

stone was composed largely of Pliocene shells, as determined by Doctor Dall. Eldridge remarks: "In view of the supposed age of the serpentine, it is thought that the deposit was formed by the accumulation of sediment and shells in a crevice of the older rocks at the time they perhaps formed the sea bluffs."

The same writer published a brief summary of his knowledge concerning the Santa Maria district in 1903.^a

The San Luis folio,^b by H. W. Fairbanks, issued in 1904, contains much that relates to the district in general, although it pertains directly only to the part containing the Arroyo Grande field. It is the most comprehensive report concerning the northwestern part of the Santa Maria district yet published.

The present writers have published two papers concerning the geology and economic resources of the Santa Maria district. The first is entitled "Diatomaceous deposits of northern Santa Barbara County, Cal.,"^c and the second "Preliminary report on the Santa Maria oil district, Santa Barbara County, Cal."^d A third paper treating more in detail the burning of the shale is "Metamorphism by combustion of the hydrocarbons in the oil-bearing shale of California," to be published in the Journal of Geology.

EARLY HISTORY OF THE DISTRICT.

The Santa Maria district was up to 1899 entirely unknown as an oil-producing territory. To Messrs. McKay and Mulholland, of Los Angeles, is due the credit for starting operations in the Santa Maria field proper. After a favorable report had been made by Mr. Mulholland on certain lands of the Careaga ranch, the Western Union



GEOGRAPHY AND TOPOGRAPHY.

LOCATION.

The region discussed in this paper is situated on the California coast in Santa Barbara County, between 120° and $120^{\circ} 40'$ west longitude and $34^{\circ} 30'$ and 35° north latitude. In areal extent it is about 1,300 square miles and it practically covers the Lompoc and Guadalupe quadrangles as topographically mapped by the United States Geological Survey. It includes portions of the San Rafael and Santa Ynez divisions of the Coast Ranges and the basin region lying between them, which is occupied by the Santa Maria, Los Alamos, and Santa Ynez valleys and the intervening hill ranges. It is bordered on the north by the San Luis Obispo County line, on the west and south by the Pacific Ocean, and on the east by the Santa Ynez quadrangle, which covers the high, wild mountains north of Santa Barbara. On its west coast are Point Sal and Point Arguello, and the south coast includes Point Conception and part of the long, straight shore line that runs due east from that point toward Santa Barbara. These are among the most prominent coastal features of California.

The region is thoroughly intersected by roads, except in some of the uninhabited portions. The Southern Pacific Railroad coast line, part of the transcontinental system, extends close to the ocean entirely around two sides of the area, and the Pacific Coast Railroad, a local line from Port Harford and San Luis Obispo, runs into the region as far as Los Olivos via Santa Maria. A rough estimate would place the number of inhabitants of this region between 5,000 and 10,000.

The Arroyo Grande and Huasna oil fields, in the San Luis quadrangle, San Luis Obispo County, are also briefly mentioned, although not a part of the region whose general features are described in this report.

DEFINITIONS OF PLACE NAMES.

The following list defines certain place names as used on the map and in this report. The two main mountain ranges have heretofore been indefinitely designated. The other names are newly applied.

The only land comprised within the Guadalupe quadrangle is the narrow strip of coast west of longitude $120^{\circ} 30' W$. The Lompoc quadrangle covers the rest of the area shown on the map east of that line.

The San Rafael Mountains include the whole group between Santa Ynez and Cuyama rivers.

The Santa Ynez Mountains include the whole range east of Point Arguello between Santa Ynez River and the ocean.

The Casmalia Hills include the group extending from the coast at Point Sal to Graciosa and Harris canyons and San Antonio Valley.

The Solomon Hills lie between the Santa Maria Valley, Foxen Canyon, and the Los Alamos Valley, and between Divide and La Zaca Creek.

The Purisima Hills lie between Lompoc, the Santa Rita Valley, and the Santa Ynez Valley on the south and the Los Alamos Valley on the north, and between Burton Mesa on the west and Alamo Pintado Creek on the east.

The Santa Rita Hills lie between the Santa Ynez and Santa Rita valleys, extending from a point east of Lompoc nearly to the east edge of the Santa Rosa grant.

The name San Antonio terrace is applied to the wide terraced region between Casmalia and the west end of the Los Alamos Valley.

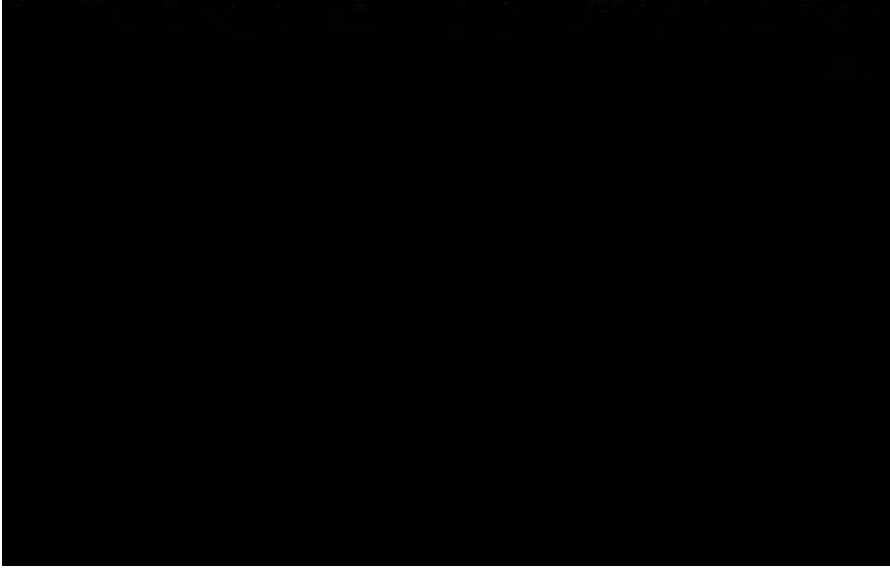
The Lompoc terrace is the plateau-like region of hills extending from the coast a distance of about 5 miles east from Honda and the same distance southeast from Surf.

In 1896 H. W. Fairbanks used the names "Point Sal Ridge" for the axis of the hills between Mount Lospe and Point Sal, and "Lions Head" for a high, rugged mass of serpentine on the coast south of Point Sal. These features are so named here.

RELIEF.

GENERAL STATEMENT.

The general character of the region covered by the Lompoc and Guadalupe quadrangles is that of a triangular hilly basin opening out toward the coast between two divergent ranges of mountains—the



They are topographically and structurally young ranges, except the Casmalia Hills, at the extremity of the northern line, which have the character of a separate and old range.

SAN RAFAEL MOUNTAINS.

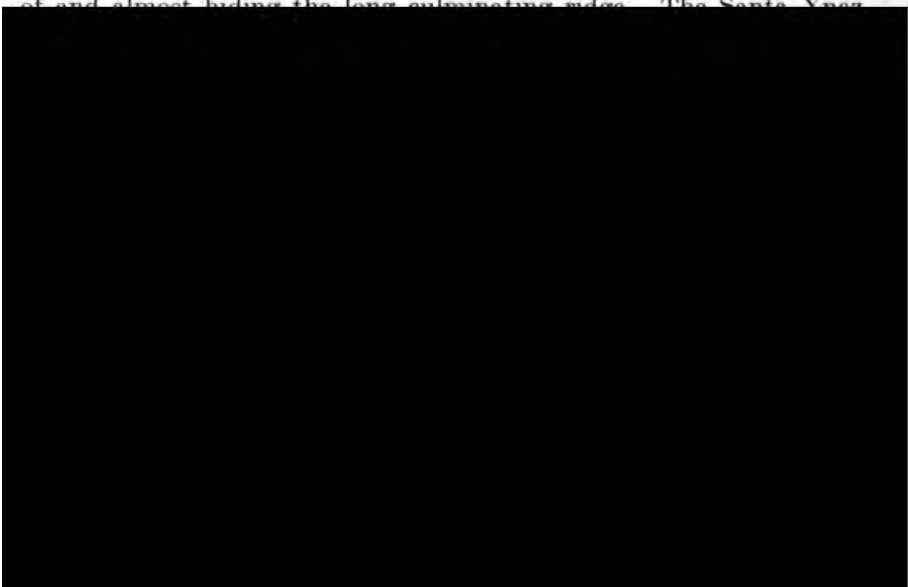
The most prominent topographic feature is the great mass of the San Rafael Mountains on the northeast and east, 25 to 30 miles back from the ocean. The structural trend of the range is N. 50° W., approximately parallel with the general course of the lines of structure in California, although on the whole more westerly. The range runs obliquely to the north-south coast line west of it, but farther north, where the Santa Lucia Range, its northward continuation, approaches the ocean the coast curves to the northwest under the control of the mountains.

Although the portion of the San Rafael Range included within the area shown on Pl. I (pocket) composes a high, rugged maze of ridges reaching elevations that range between 2,000 and 4,300 feet, this portion is in the larger aspect, but subsidiary to the main mountain group farther east, in which altitudes approaching 9,000 feet are attained. The ridges are divided by steep canyons, most of which cut transversely across the formations regardless of the folding and structural lines. Rounded soil-covered slopes form a considerable portion of the part of this range included in the Lompoc quadrangle, but rough, rocky slopes are likewise abundant. The range is traversed centrally by the well-graded canyon of Sisquoc River, which divides it into two mountain groups. On the south and north the range is bounded by wider graded valleys—those of Santa Ynez and Cuyama rivers. The Santa Ynez divides two distinct ranges. The Cuyama forms a more arbitrary division in the Coast Ranges. Near its mouth, at the point where it reaches the area included in the accompanying map, it veers to the south and cuts a narrow gorge across the San Rafael Mountains without regard to the structure. The range may be regarded as continuous across this portion of the river.

Within the triangular area mapped the high ridges and mountains around Zaca Lake, Bone Mountain, Tepusquet Peak, and Los Coches Mountain are boldly defined, with steep side slopes descending into narrow canyons, and as a rule rounded summits. The broad ridge originating north of Los Coches Mountain and extending southeastward to North Fork of Labrea Creek, where its character is temporarily lost until it appears again in Manzanita Mountain, is a striking feature with its long southwestern and abrupt northeastern slopes. The seaward flanks of the range terminate rather abruptly in the terraces bordering the Santa Maria Valley.

· SANTA YNEZ MOUNTAINS.

The Santa Ynez Mountains form a long, narrow range bordering the Santa Barbara Channel and bounded on the north by the westward flowing Santa Ynez River. The trend of the range is east and west and has determined the unusual direction taken by the coast south of it. The range is about 9 miles in average width and contains two lengthwise zones. The southern zone comprises a ridge with remarkably even sky line, which rises directly from the sea. This ridge increases in height toward the east from an elevation of 1,000 feet at Point Conception to 3,800 feet east of Refugio Pass and more beyond the boundary of the area mapped. At Point Conception the coast bends abruptly to the northwest around the end of this ridge, but north of Jalama Creek a similar ridge, that of the mountain El Tranquillon, follows the coast as far as Point Arguello, where the shore bends again abruptly and assumes a northward course. The second zone lies between these two coast ridges and Santa Ynez River. It has more the nature of a foothill region, forming a partly individual range of hills and ridges separated from the coastal ridge by longitudinal valleys. The average slope from the summit of the range down to the sea is at an angle of 20° to 30° . In places the angle is less, but on some individual slopes it is greater. The width of the range on the north of the summit ridge is greater and the slope more gentle and more broken than on the southern abrupt slope to the sea. Viewed from the ocean on the south the range has the appearance of a steep, even-topped breastwork; from the north it appears as a belt of discontinuous hills and ridges grouped in front of and almost hiding the long culminating ridge. The Santa Ynez



and opposed by the east-west structure of the Santa Ynez Range, and the result is this convergence of ranges with the consequent formation of a high, structurally complex region. The Lompoc quadrangle is on the western outskirts of this region, and the lines of relief corresponding to the two lines of structure are here beginning to diverge and show their individuality in the two bounding ranges.

SANTA MARIA VALLEY.

Santa Maria River, which takes its rise in two profound valleys within the San Rafael Range, flows along the foot of this range at the north edge of the Santa Maria Valley. This valley is a wide flood plain with an even cultivated floor, surrounded by low terraces that fringe the base of the mountains on the northeast and rise into the Solomon Hills on the south. It opens out to the sea and forms the southern part of the low region lying between Pismo Beach in San Luis Obispo County and the Casmalia Hills.

CASMALIA HILLS.

The most prominent feature of the landscape south of the Santa Maria Valley is a long ridge with a level sky line running northward out to the ocean at Point Sal. This is the high ridge of the Casmalia Hills, which rises abruptly from the Santa Maria Valley. Its highest point is Mount Lospe, 1,624 feet above the sea. The slope up to this ridge from the valley on the northeast is steep, but on the north the rise is more gradual over wide slopes of dune sand. On the southeast the ridge declines as it approaches Schumann Pass, the low divide over which the railroad crosses from the Santa Maria Valley to Schumann Canyon; on the south it forks into successive ridges which slope gradually into terraced hilltops bordering Schumann Canyon; on the west it drops off abruptly into steep, rocky declivities that fringe the sea in the neighborhood of Point Sal. The ridges continue southeastward opposite Schumann Pass as far as Graciosa Canyon, where they sink under more recent sand formations and lose their character. South of Schumann Canyon the terraced slope continues in the San Antonio terrace as a wide plateau locally intersected by sharply defined U-shaped canyons. The Casmalia Hills, particularly that portion north of Schumann Canyon, have a distinct individuality among the topographic features of the basin region, and may be regarded as a separate although small range allied in age and character with the bounding ranges. It is conformable in trend with the San Rafael Mountains and forms a prominent headland jutting out to sea.

Most of the ridges in these hills follow the strike of the beds. Their summits are characteristically of gentle incline; the side slopes

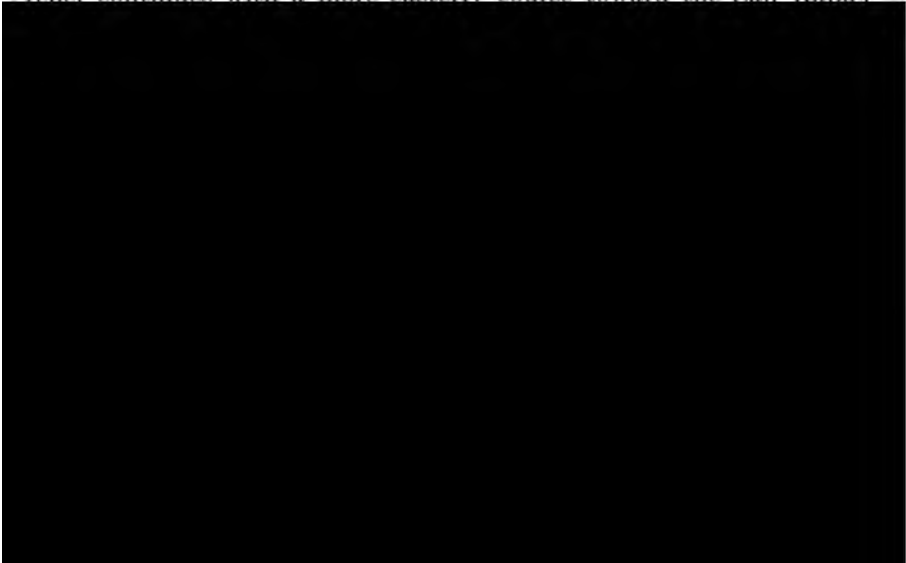
range from gentle to fairly steep, being in many places determined by the dip. Pl. IX, A (p. 80) shows excellent examples of the strike ridges, dip slopes, and even sky lines of these hills. The ridges diverging from Mount Lospe are given prominence by the hard flint of which they are formed, and the sharp outlines of the slopes along the coast southward from Point Sal are caused by the resistant igneous rocks there exposed.

South of the Casmalia Hills the sea has cut into soft formations and along structural lines, so as to leave the Point Sal Ridge jutting out as a promontory. The same is true on a smaller scale south of Purisima Point, the seaward extension of Burton Mesa, and south of the west end of the Santa Ynez Range. The coast north of each of these headlands runs northward, with only a gentle curve away from the point, until the indentation south of the next range is reached. The east-west coast lines follow structural features; the north-south lines truncate them. Faults are not concerned in any of the north-south features along this part of the coast.

North of the Casmalia Hills the coast forms a straight north-south line bordering the lowland that opens out at the mouth of the Santa Maria Valley as far as the deep indentation at the base of the San Luis Range, which exhibits the best example of this type of coastal structure. The latter range lies in the San Luis quadrangle and has been described in the folio covering that region.^a

SOLOMON HILLS.

Although the Casmalia Hills drop into insignificance in the vicinity of Graciosa and Harris canyons, their general line of topographic relief continues with a more easterly course toward the San Rafael



as high as 1,600 feet. A common height for summits in these hills is 1,200 feet.

Wide, shallow, filled valleys between the rolling summits are characteristic of the Solomon Hills, the soft valley filling being as a rule sharply cut along a meandering course by a miniature stream gorge that has been rapidly eroded. Many of these recent channels are deeper than they are wide. In the vicinity of La Zaca Creek on the east the Solomon Hills merge with these foothills, and the general topographic features are continued in them. The Solomon Hills owe their low outlines largely to their structural development rather than to their topographic maturity. It has been an area of building up as well as of wearing away, and the original topography, which reflected characteristically the folds of the sedimentary formations, has been obscured by further deposition and by the filling of valleys, in addition to alteration by erosion.

LOS ALAMOS VALLEY.

The incline of the Solomon Hills on the south is gradual down to the Los Alamos Valley. This valley extends from the region where the Solomon and Purisima hills coalesce in the foothills of the San Rafael Range a distance of about 27 miles to the coast, in a direction about N. 75° W. This, it will be noted, is much more westerly than the trend of the Santa Maria Valley. The Los Alamos Valley separates the two basin ranges—the Solomon and Purisima hills—and is a drainage feature of them alone. The average altitude at the summit of its watershed is from 1,000 to 1,300 feet; and the highest elevation that the watershed reaches anywhere is less than 2,000 feet. All the water from the higher surrounding regions that drains into the Santa Maria basin region escapes either into the Santa Maria Valley on the north or the Santa Ynez Valley on the south.

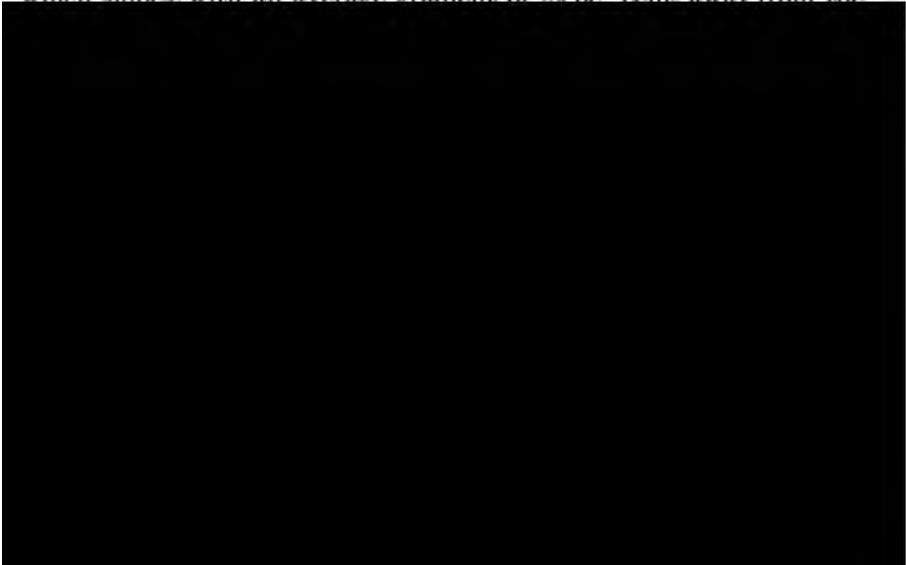
PURISIMA HILLS.

The second of the two hill ranges is that of the Purisima Hills, which forms a definitely outlined structural and topographic unit springing from the plateau region about Santa Ynez and the foothills of the San Rafael Range in the vertex of the triangular basin. It rises at that point in the shape of a number of strike ridges which run north-westward and then curve around to the west, coming together. For most of the distance to the ocean beyond this junction the range consists of a single ridge running parallel to the Los Alamos Valley. On the north it sends out lateral ridges that drop off rather abruptly into the Los Alamos Valley. These ridges are separated by fairly sharp V-shaped valleys, although some of the valleys have sides of more gentle slope and filled bottoms. A striking topographic feature is a

longitudinal trough running for miles parallel with this range and the Los Alamos Valley and cutting across the ends of the above-mentioned ridges at right angles to them, at a distance of one-half to 1 mile from the valley. It notches all the ridges and leaves an individual row of knobs 100 to 200 feet in relief bordering the valley. This depression is not a continuous drainage feature, but is stratigraphically of importance as approximately marking the contact between the Monterey shale and the loose Fernando sand. On the south side of the summit of the Purisima Hills the lateral ridges extend a long way with a uniform gentle slope, like remnants of an eroded inclined plateau. At their base, some miles from the summit, and usually from 500 to 1,000 feet below, these southern slopes merge into an undulating hilly plateau that has the appearance of being buried under soft recent sand. The range is broadest at the east end, where it consists of a number of parallel ridges. The point of convergence of some of these is Redrock Mountain, which is 1,968 feet high and the highest summit in these hills. Thence westward the hilly zone narrows into a single central ridge and its offshoots, and gradually pinches out, finally giving place on the south and west to a broad terrace in which its hilly character is lost. The summit of the main ridge of the Purisima Hills west of Redrock Mountain gradually declines in height and for most of the way it is remarkably even, the elevation varying between 1,200 and 1,000 feet. At the elevation of 1,000 feet it grades into the smooth terrace called Burton Mesa.

BURTON MESA.

Burton Mesa is a marine terrace covering more than 50 square miles, which slopes with an average gradient of 24 per cent. away from the



of Canada Tortuga the steeper portion above the coastal bench is only 100 feet high, and in the northwest corner of the mesa the main terrace and the coastal bench grade into each other and become practically one.

SANTA YNEZ VALLEY AND SANTA RITA HILLS.

Santa Ynez River is the second of the two main drainage lines of the area, Los Alamos Creek, the next in size, being much subordinate to these two. The Santa Ynez rises in the high region north of Santa Barbara and flows westward between the Santa Ynez and San Rafael ranges. From the east edge of the Lompoc quadrangle, where these two ranges diverge, it flows slightly to the north of west, at the foot of the Santa Ynez Mountains. Its course is even more westerly than that of the Los Alamos Valley until it approaches the ocean, where the nose of the Santa Ynez Range, as in the two ranges farther north, shows a tendency to change its orientation into greater conformity with the northwesterly course of the San Rafael Range.

This stream has a low gradient of only one-fourth of 1 per cent. Its valley has a steep side on the south formed by the hills of the Santa Ynez Range, but it is widened on the north by the easy slopes of terraces and sand hills, except at the Santa Rita Hills, which rise midway in the river's course.

The Santa Rita Hills form a small separate range reaching a height of 1,300 feet and resembling in miniature the Purisima Hills. The range starts from the valley in several strike ridges running northwest, which join in the highest part of the range and then continue due west as a single ridge. The river follows a tortuous course between this and the Santa Ynez Range and has cut cliffs in many places. On the north the Santa Rita Hills are divided from the Purisima Hills by the Santa Rita Valley, a low basin similar to some portions of the Santa Ynez Valley.

The level floor of the river valley, including the stream bed and the somewhat higher terrace-like flats on either side, ranges in width from a few hundred feet to about a mile until within 10 miles of the ocean, where it opens out into the Lompoc Valley, an alluvial flat several miles wide.

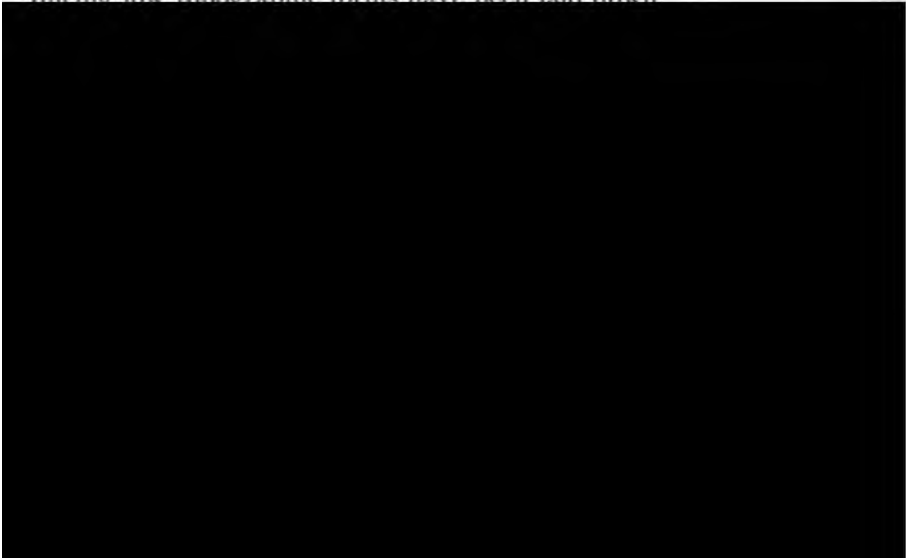
TERRACED COAST.

Pleistocene terraces border the coast for the greater part of the distance around the Guadalupe and Lompoc quadrangles. The great Burton Mesa terrace has already been mentioned. Beyond the valleys to the north and south of this mesa similar terraced areas extend widely and in places to a considerable distance inland, but nowhere else with so gentle a slope as is exhibited on the Burton Mesa.

Where steep hills descend toward the coast there is almost without exception a coastal terrace starting at the top of the sea cliff, which, as a rule, ranges in height from a few feet to more than 50 feet above the water. Most of these terraces extend up to an elevation greater than 200 feet. Some of them have left traces at a height of 300 feet or more, and others continue perfect to this altitude or even higher.

GENERAL TOPOGRAPHIC FEATURES.

The point of especial interest in the topography of the central region between the two bounding ranges is its characteristic reflection of the structure of the formations, whereas in the mountains, as has been noted, the topographic development has been less in accordance with the lines of structure. An anticline in the central region is apt to be coincident with a ridge, as, for example, in the long ridge of the Purisima Hills, which lies close to the axis of a broad anticline. Moreover, some of the larger valleys mark the synclinal axes of the broad lines of structure—a statement illustrated by the Santa Ynez Valley in parts and by its structural, although not actual, continuation in the Santa Rita Valley. It is also exemplified by the upper portion of the Los Alamos Valley and by Harris Canyon. These topographic features may be accounted for by the facts that the main movements in these hill ranges have been gentle as compared with those in the older mountain masses, that the disturbances giving them form have been comparatively recent, and that deformation has not gone so very far. Wherever there are low areas of rolling hills it is almost sure to be found that a syncline or plunging fold has given rise to structural depressions in which deposits of soft sand producing low topographic forms have been laid down.



and having a dip slope, as shown in Pl. IX, A (p. 80). Characteristic of the soft shale are hills having the form of mounds with symmetrical rounded contours and with few prominent outcrops except pavements of shale forming the surface. The soft Fernando sands form small hills that look like irregular sand piles, and long slopes with shallow erosion features. Some of these slopes reflect the dip of the strata on the flanks of low folds and are structurally inclined plateaus in a typical state of youthful dissection. The valleys are, in many places, filled with sand that has shifted down from the hills faster than it could be carried away by agencies of transportation. Great cliffs of soft sand are common as the result of the rapid undermining and removal of portions of hills. Thus walled cirques are formed. Harder materials in the Fernando cause squarish forms, such as that of Mount Solomon. The terraces of the Quaternary give a strong individuality to the topography of this region. They are widely in evidence along the coast, in valleys, at all levels up to 1,200 or 1,400 feet on slopes, on hilltops, and along horizon lines.

DRAINAGE AND RAINFALL.

The three principal streams have received mention under the previous headings. A small amount of water runs in them all the year round, but the quantity is only rarely sufficient in either of the two main streams to warrant their being called rivers. This name is applied to them on the ground of the importance of their drainage areas. Almost all the drainage of the two quadrangles flows into these three streams. In the main they run parallel to the strike of the formations. In addition to those already mentioned, others that run independently into the sea are Casmalia Creek, in Schumann Canyon, which first cuts obliquely across the end of the Casmalia Hills and then assumes a longitudinal course; Canada Honda Creek and Jalama Creek, the two last having deeply cut courses parallel with the structural lines at the west end of the Santa Ynez Mountains. The steep seaward slope of these mountains is cut into by a great number of short, steep, transverse gorges.

The portion of the San Rafael Range lying within the area covered by the map is drained principally by Sisquoc and Cuyama rivers, which flow along well-graded courses, and by the minor streams, Labrea and Tepusquet creeks. With the exception of the Cuyama, these watercourses and the majority of the others in the mountains have cut transverse canyons across the formations regardless of the folding and the structural lines. In this respect they differ from the streams farther south.

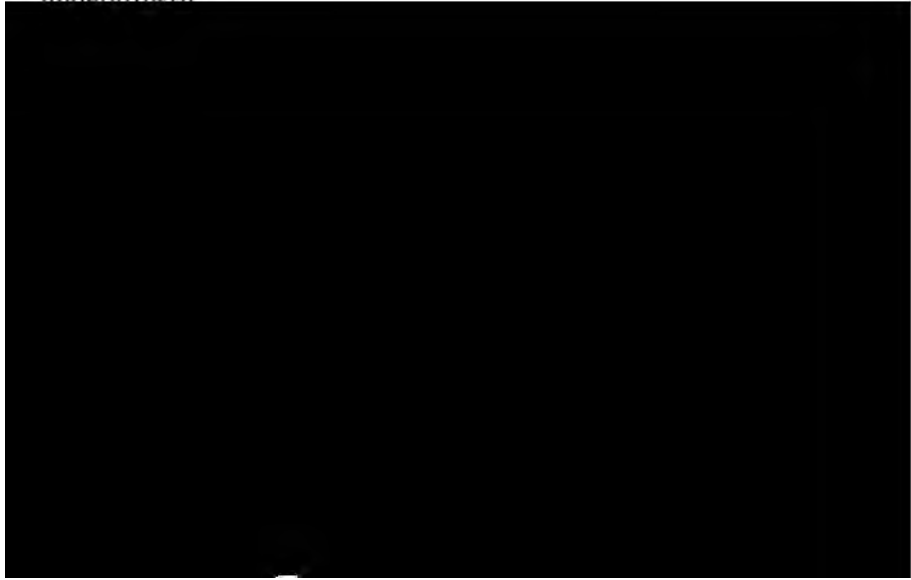
On the whole, it is rather a dry region. An average of only 12 or 15 inches of rain falls annually, during the winter rainy season. During

the long dry season almost complete evaporation of surface moisture takes place, and there is little erosion through the aid of water. Throughout the latter part of the Quaternary period the rate of erosion has probably been slow.

CLIMATE AND VEGETATION.

The climate of this area is that of the coastal region of California. It is equable the whole year round, excessive heat or cold being very rare. The days are mild, the nights chilly. The region is subject to the inroads of heavy fogs and driving winds from the open ocean, but this is true to a lesser degree in the eastern angle of the basin, where there are protecting hills on all sides. The winds blow very strongly from the west and northwest up the radiating valleys that open to the coast. The region is subject to earthquakes, some of which would seem to be of local origin.

The vegetation in the northern part of Santa Barbara County is open, as in the neighboring portions of California. There are almost no dense groves of trees, most of the hills being sparsely clothed with a scattering growth of small trees, usually live and white oaks, and bushes, or else entirely bare, except for sagebrush and grass. The wide terraces and hills of soft sand are commonly overgrown with so-called tarweed and are otherwise almost bare. In the valleys near the coast grow many willows; in the more protected valleys farther inland thrive large sycamores, cottonwoods, and live and white oaks. The steep slopes of the San Rafael Range are sparsely set with small oaks, pines, and yuccas, and, like those of the Santa Ynez Range, are covered in parts by dense thickets of undergrowth.



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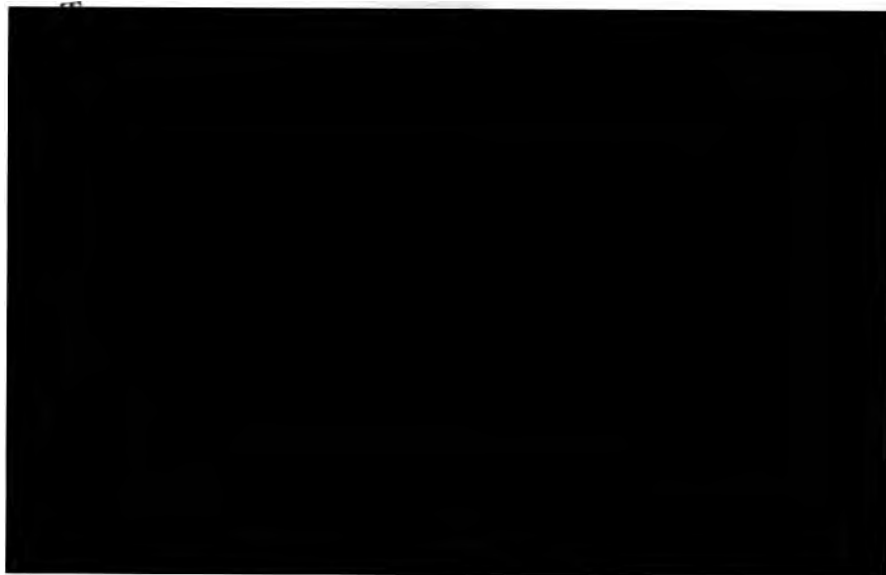
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standard California section and with that of Santa Clara Valley, Ventura County:

Tentative correlation of formations of Santa Maria district with the standard California Coast Range section and with that of the Santa Clara Valley.

Era.	System.	Period.	Standard Coast Range section.	Santa Maria district section.	Santa Clara Valley section.
Cenozoic.	Quaternary.	Recent.	Alluvium.	Alluvium.	Alluvium.
		Pleistocene.	San Pedro.	Terrace deposits and dune sand.	Sand and gravel.
			— Unconformity —	— Unconformity —	— Unconformity —
	Tertiary.	Pliocene.	Merced.	Fernando.	Fernando.
			Purisima.		
		Miocene.	San Pablo.	— Unconformity —	— Unconformity —
			— Unconformity —		
			Monterey.	Monterey.	Modelo. { Shale. Upper sandstone. Shale. Lower sandstone.
			Vaqueros.		Vaqueros.
		Oligocene.	San Lorenzo.	Vaqueros, Sespe, and Tejon, undifferentiated (including some Monterey in Santa Ynez Range).	Sespe. { Upper. Red beds. Lower.
			— Unconformity? —		
		Eocene.	Tejon.		Topatopa.
			Martinez.		
Mesozoic.	Cretaceous.		— Unconformity? —	(?)	(?)
			Chico.		
			— Unconformity —		
			Horsetown.		
			— Unconformity —		
			Knoxville.	Knoxville.	
	Jurassic (?).		— Unconformity —	Franciscan.	— Unconformity — Granite, gneiss, etc.
			Franciscan.		
			— Unconformity —		
			Granite, schist, etc.		

FRANCISCAN FORMATION (JURASSIC?).

The oldest rocks within the Santa Maria district belong to the Franciscan formation, which is probably of Jurassic age. H. W. Fairbanks described the same formation under the name San Luis in the San Luis folio. The Franciscan is a very important basement formation in the Coast Ranges farther north. The small areas of these rocks occurring here consist of remnants of beds of sandstone, shale, glaucophane schist, and jasper associated with serpentine that has probably been intrusive in them. The sandstone is usually of a dark-green color, fairly fine grained, and considerably indurated. The jasper is banded by thin contorted beds. These sediments are so

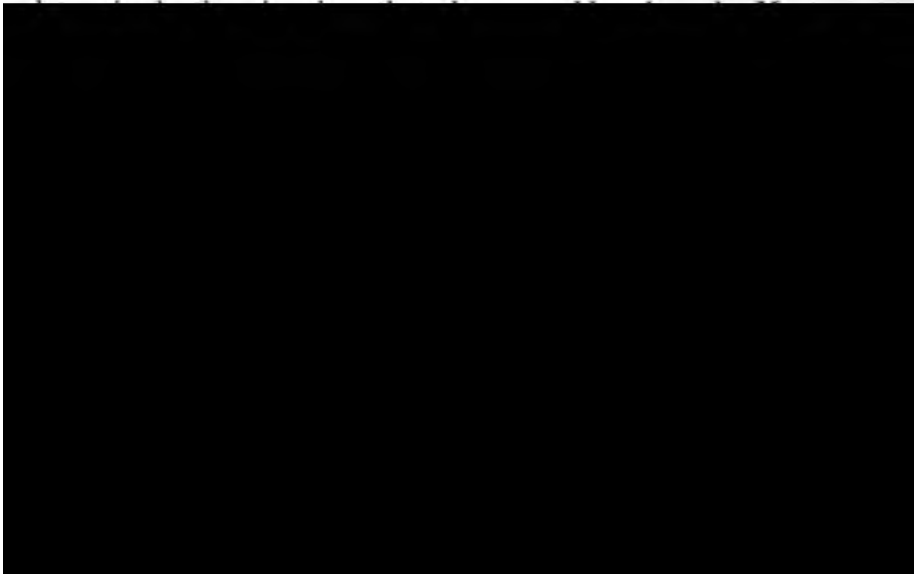
disturbed that little clew as to their structure can be obtained, and so local in extent that no attempt has been made in mapping to differentiate them from the accompanying serpentine.

KNOXVILLE FORMATION (LOWER CRETACEOUS).

Several small areas of sedimentary rock occur which can be definitely assigned on fossil evidence to the Knoxville, or lower Cretaceous. The two most important are north of Mount Lospe, in the Casmalia Hills. The rock is chiefly dark-colored, unaltered argillaceous shale, such as is characteristic of the Knoxville throughout its wide area of distribution in the California Coast Ranges. Sandstone and conglomerate occur in lesser amounts. Brownish-yellow sandstone, similar to that common in the Knoxville in the Coast Ranges several hundred miles farther north, occurs on the border of an irregular area of diabase on Tepusquet Creek, in the San Rafael Mountains, and contains the characteristic Knoxville fossil *Aucella piochii* Gabb (Pl. XIII, figs. 1, 2, 3a, 3b, p. 128). The rock is present only in very small patches, and seems to have been brought up from below by the diabase intrusion. The Knoxville was recognized in one other place in the San Rafael Mountains a few miles north of Zaca Lake, at the base of the series mapped as pre-Monterey, where also it contains *Aucella piochii*. It is very likely that a portion of the areas mapped as pre-Monterey belongs to the lower Cretaceous, but it is not probable that the whole does.

PRE-MONTEREY ROCKS.

Two large areas of sedimentary rocks whose age has not been



has been considered upper Cretaceous and of one in southeastern Santa Barbara County that has been ascribed to the Eocene. Its age is therefore much in doubt. It may also include at the top part of the Vaqueros (lower Miocene), which overlies this doubtful terrane and of which the base has not been definitely determined.

Structurally the strata included in this pre-Monterey group lie beneath the Monterey and upper Vaqueros, but though far older they do not bear so strongly the marks of intense folding as do the brittle Monterey shales. They are, however, steeply upturned, and the lines of folding, as in the case of the other formations, are in general in a northwest-southeast direction.

TEJON, SESPE, AND VAQUEROS FORMATIONS, UNDIFFERENTIATED
(EOCENE-MIOCENE).

GENERAL STATEMENT.

The Santa Ynez Range is mostly composed of a thick terrane of marine sediments equivalent to a part or all of the Tejon formation and the Vaqueros formation. The former is Eocene and the latter lower Miocene in age. This terrane comprises a continuous succession of marine sediments of detrital origin, seeming to present no point at which an angular unconformity exists, although the line at the base of the coarse conglomerate containing the Vaqueros fossils doubtless marks a long time interval.

In the preliminary report on the Santa Maria district^a mention is made of the Sespe formation as being represented here, and a small area of it is shown on the map accompanying that report. The Sespe formation belongs to the Eocene or Oligocene and is a distinct formation above the Tejon and below the Vaqueros. It occurs extensively in the Santa Ynez Mountains north of Santa Barbara, and an outcrop of blood-red sandstone in this range $3\frac{1}{2}$ miles south of the Santa Ynez Mission was indicated on the outline map as belonging to the Sespe because of its lithologic resemblance to the typical rocks of this formation. This small area has, however, not been separately shown on the present map, as there is no good proof of its age. It is quite possible that the Sespe formation is represented in parts of this western portion of the range by rocks not recognizable on the lithologic grounds which are deemed sufficient for the determination of this formation in the vicinity of Santa Barbara or the Ojai Valley, to the east; or it may be that sedimentation was not operative in the western part of the range during Sespe time, and therefore that rocks of that age are lacking from the geologic section in this region. The amount of work done in the Santa Ynez Range does not warrant a full discussion of the structure and relations of

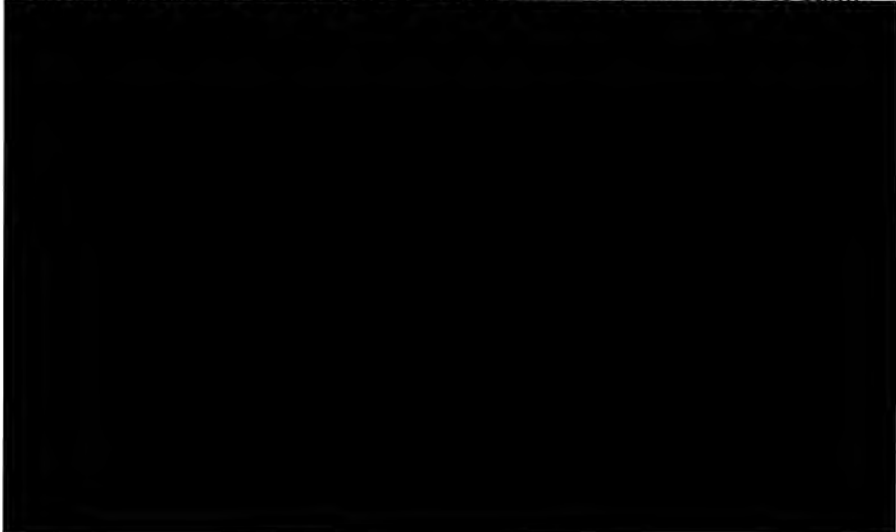
^aBull. U. S. Geol. Survey No. 317, 1907, pp. 1-69.

its rocks stratigraphically below the base of the Monterey (middle Miocene) shale.

Strata corresponding to the upper portion of the Tejon-Sespe-Vaqueros terrane have been recognized also in the San Rafael Mountains, where they are exposed at the base of the Monterey (middle Miocene), and it may be that the pre-Monterey rocks are in part equivalent to the lower portion of this terrane. The Vaqueros and possibly part of the Tejon are present also in the Casmalia Hills.

LITHOLOGIC CHARACTER.

The lower portion of the terrane is made up of a thick series of greenish-gray coarse and fine sandstones, many of them concretionary in character, interbedded with dark, fine-grained, thin-bedded shales in lesser amount. Toward the middle of the terrane the shale increases in amount, alternating with thin beds of sandstone. Much of the shale has a characteristic olive-gray color, and owing to its hard, gritty, brittle nature it makes excellent road material for the Santa Ynez Valley. The shales and sandstones give place above the middle of the terrane to deposits of shallow-water character—coarse sandstone and a great quantity of coarse, in many places greenish or reddish, gravelly conglomerate. This conglomerate contains abundant Vaqueros fossils and probably represents the base of that formation and a period of shallow-water conditions with which the Vaqueros began. The conglomerate gives place in turn to more shale and sandstone, which continue to the summit of the terrane. At the top there is a conformable gradation into the Monterey (middle Miocene) beds, the summit of the Vaqueros being marked by a calcareous zone in many places—as, for instance, southwest of Lom-



shale is mentioned by H. W. Fairbanks in the two quotations given under the heading "Previous knowledge of the geology," pages 12-13, and this author discusses them further in his paper there cited.

STRUCTURE AND THICKNESS.

Like all the Tertiary and pre-Tertiary formations of this region the deposits under discussion have been subjected to folding that has left none of them in an undisturbed attitude. But as they consist in large part of soft sandstone and conglomerate with interbedded layers of sandstone and clayey shale, they have not been so violently fractured and disturbed as much of the brittle shale of the lower portion of the Monterey (middle Miocene). The high ridge of the Santa Ynez Mountains from Point Conception eastward is formed by a great monocline in the sandstone of this terrane, dipping toward the sea on the south at an angle of about 30°. North of this ridge occurs a longitudinal depression in the range in which the folds of the beds are rather low; and still farther north, bordering the Santa Ynez Valley, these rocks are considerably disturbed, dipping in various directions and at all angles between 15° and the vertical. The general inclination of the beds on the north side, however, is northward, the structure of this part of the range, broadly viewed, being anticlinal. In the San Rafael Mountains the Vaqueros strata are steeply folded along northwest-southeast lines, in conformity with the overlying Monterey. A marked example of the way in which the soft, coarse conglomerate has been left little affected occurs in Buckhorn Canyon, where thick beds of this rock, probably the basal part of the Vaqueros, lie almost horizontal.

The Tejon-Sespe-Vaqueros rocks have a thickness of at least 5,000 feet in the Santa Ynez Mountains, and further work will probably allow these figures to be considerably increased.

AGE AND FOSSILS.

At least two distinct faunas are found in the Tejon-Sespe-Vaqueros strata. The lower is characteristically Eocene, and similar to that of the Tejon formation of the type locality; the upper contains many of the species found at the type locality of the Vaqueros formation, which is the standard lower Miocene of the central California province. So far as is definitely known no species bridges the gap between these two faunas, either here or elsewhere in California, although the beds containing the two are apparently conformable not only in the Santa Ynez Range but also locally as far north as Martinez, east of San Francisco Bay.

The following tables show the fossiliferous Tejon and Vaqueros localities and the species of fossils found at each. (See map, Pl. I, in pocket; and illustrations of fossils, Pls. XII to XXVI, pp. 126-154.)

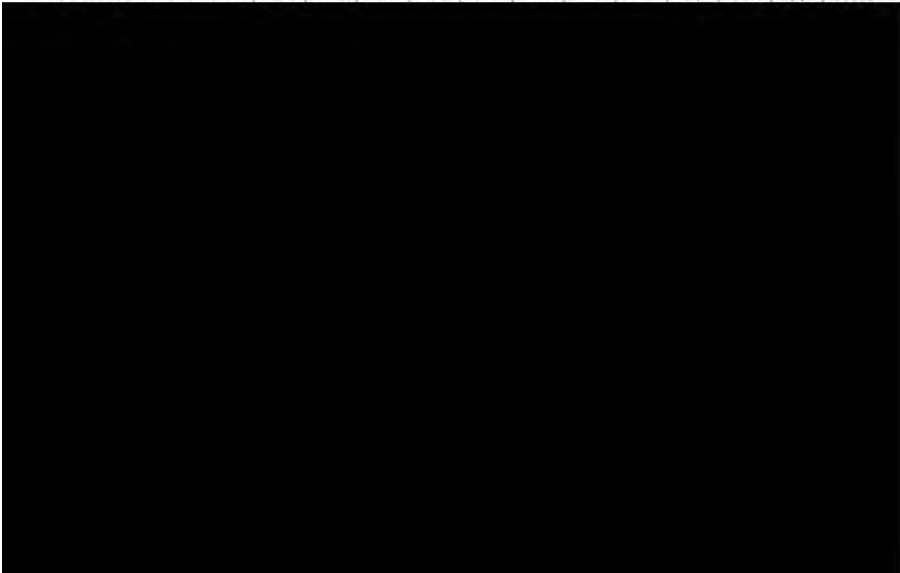
Tejon (Eocene) fossils from the Santa Maria district, California.

	4507.	4509.	4513.	4518.
<i>Cardium breweri</i> Gabb (Pl. XII, fig. 1).....	X			X
<i>Codakia?</i> sp. a.....	X			X
<i>Conus</i> cf. <i>hornii</i> Gabb.....	X	X		X
<i>Crassatellites collina</i> Conrad (Pl. XII, figs. 2a, 2b, 3).....	X			X
<i>Dosinia elevata</i> Gabb.....	X			X
<i>Fusus occidentalis</i> Gabb.....	X		X	X
<i>Ficus mamillatus</i> Gabb (Pl. XII, figs. 5a, 5b).....	X			X
<i>Glycymeris</i> cf. <i>veatchii</i> Gabb var. <i>major</i> Stanton.....	X	X		X
<i>Mactra</i> cf. <i>uvasana</i> Conrad.....			X	
<i>Meretrix uvasana</i> Conrad.....	X			
<i>Meretrix</i> sp.....			X	
<i>Neverita?</i> sp.....			X	
<i>Nucula truncata</i> Gabb.....				X
<i>Ostrea idriaensis</i> Gabb (Pl. XIV, figs. 1a, 1b).....	X			X
<i>Pecten</i> (<i>Chlamys</i>) <i>yneziana</i> Arnold (Pl. XII, fig. 4; Pl. XIII, figs. 6a, 6b).....	X	X		X
<i>Phacoides cumulata</i> Gabb (Pl. XIV, fig. 2).....				X
<i>Phacoides</i> (<i>Miltha?</i>) sp.....	X			
<i>Tellina?</i> sp.....		X		
<i>Turritella</i> (<i>martinezensis</i> Gabb var.?) <i>lompocensis</i> Arnold (Pl. XIII, figs. 5a, 5b, 8).....		X		
<i>Turritella uvasana</i> Conrad (Pl. XII, fig. 6; Pl. XIII, fig. 7).....	X	X		X
<i>Venericardia planicosta</i> Lamarck (Pl. XIII, fig. 4).....	X			X

4507. Just above San Julian ranch house, 1 mile southeast of bench mark 603.
4509. Sharp turn in road in San Miguelito Canyon, 4 1/2 miles S. 20° W. of Lompoc bench mark 95.
4513. South side of El Jaro Creek road, one-half mile west of bench mark 927.
4518. Three miles north of Sudden, on north flank of 1,912-foot hill.

Vaqueros (lower Miocene) fossils from the Santa Maria district, California.

	4478.	4504.	4508.	4510.	4511.	4512.	4514.	4516.	4517.	4519.	4520.	4521.
<i>Balanus</i> cf. <i>estrellanus</i> Conrad.....									X		X	



Vaqueros (lower Miocene) fossils from the Santa Maria district, California—Continued.

	4478.	4504.	4508.	4510.	4511.	4512.	4514.	4516.	4517.	4519.	4520.	4521.
<i>Terebratalia kennedyi</i> Dall (Pl. XVII, fig. 4a, 4b, 4c, 4d).....												X
<i>Purpura vaquerosensis</i> Arnold (Pl. XV, figs. 1a, 1b).....		X										
<i>Turritella</i> sp. indet.....			X									
<i>Turritella ineziana</i> Con- rad (Pl. XVI, fig. 3).....							X	X	X			
<i>Turritella variata</i> Conrad (young?).....								X				

4478. Two miles south of Santa Ynez, on knoll just east of mouth of Ballard Canyon.

4504. Three-fourths of a mile up ridge northeast of San Julian ranch house, $1\frac{1}{4}$ miles east of bench mark 603.

4508. El Jaro Creek, one-fourth mile east of Salsipuedes Creek, southeast of Lompoc.

4510. Five miles north of Concepcion, one-fourth mile west of mouth of Escondido Creek.

4511. Float on hillside along east side of Los Amoles Creek, 1 mile above El Jaro Creek.

4512. Ridge between Los Amoles and Salsipuedes creeks, $10\frac{1}{2}$ miles S. 33° E. of Lompoc bench mark 95.

4514. About 10 miles west of Santa Ynez, on south bend of river $1\frac{1}{4}$ miles southeast of bench mark 552.

4516. South of Santa Ynez Mission, $2\frac{1}{2}$ miles up Allisal Creek, at mouth of valley on east.

4517. Three miles north of Sudden, on north flank of 1,912-foot hill, above locality 4518, which is Eocene. (See p. 29.)

4519. On ridge 2 miles east-southeast of El Jaro Creek, bench mark 603, one-half mile west of 1,111-foot hill.

4520. West side of ridge between Los Amoles and El Jaro creeks, 1 mile west of bench mark 603.

4521. Lime quarry $\frac{5}{8}$ miles southwest of Lompoc.

MONTEREY SHALE (MIDDLE MIOCENE).

GENERAL STATEMENT.

A great series of fine shales, largely of organic origin, overlies conformably the coarse and fine sedimentary deposits of the Vaqueros. These shales make up the Monterey formation and are probably representative of the whole of middle Miocene time. The series is of great thickness and is doubly important as the probable source and the present reservoir of the oil. The areal extent of the Monterey is not adequately represented on the map. It doubtless covers as one continuous sheet the whole basin between the Santa Ynez and San Rafael mountains, as well as a large part of these ranges, but it is concealed over considerable areas by later deposits, which are in many places very thin. The character, structure, and relations of the Monterey have been the chief subject of the present study.

The name Monterey was given by William P. Blake^a in the early fifties to an organic shale formation typically developed near Monterey, in central California. It is very extensive in the California Coast Ranges, being the "bituminous shale" described by Whitney^b as occurring at widely separated points north and south of the Golden Gate. Its age is generally taken as middle Miocene. It is the source of much of the petroleum found in California. The shale characteristic of this unique formation is not similar to ordinary clay shale, but is composed largely of the remains of minute marine organisms. In an

^a Proc. Acad. Nat. Sci. Philadelphia, vol. 7, 1855, pp. 328-331.

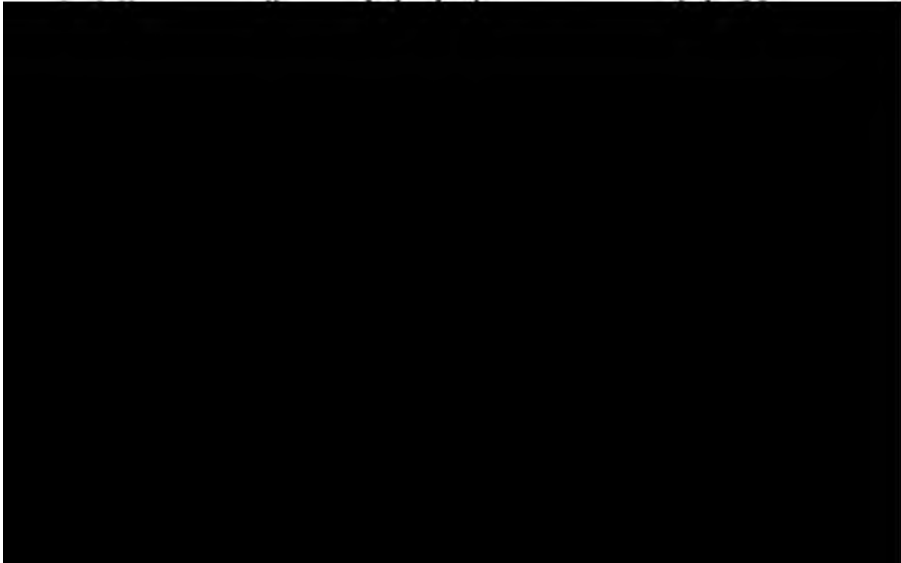
^b Geological Survey of California, Geology, vol. 1, 1865, p. 137.

unaltered condition it resembles chalk, but is of siliceous instead of calcareous composition.

The Monterey in the part of California treated here may be divided on lithologic grounds into two parts, although there seems to be perfect conformity throughout the series. There is no definite dividing line to be drawn, but taken as a whole the lower half, composed chiefly of hard, metamorphosed, in places flinty shales, is distinct from the upper half, in which soft shale, giving evidence to the naked eye of its organic origin, is predominant.

LOWER DIVISION.

The fossiliferous limestone at the top of the Vaqueros is overlain conformably by hard calcareous and flinty unfossiliferous shale characteristic of the base of the Monterey. In places the limestone at the top of the Vaqueros is not well developed, but is replaced by a series of thin-bedded, in the main fairly hard, siliceous, calcareous, and somewhat argillaceous shales of coarse and fine texture, in which no well-defined line of demarcation between the two formations is to be drawn. The Vaqueros and Monterey terranes taken as wholes are distinct units, representing periods of deposition of entirely different character. As indicated by the rocks, deposition was continuous between the Vaqueros and Monterey and the change in character came suddenly, although less so in some places than in others. The general nature of the Vaqueros series is detrital; that of the Monterey is organic. The former contains many well-preserved molluscan forms, the latter few. Close to the line between the two, beds predominatingly of a gravelly or sandy nature or those bearing fossil mollusks are considered part of the Vaqueros; those of a fine texture





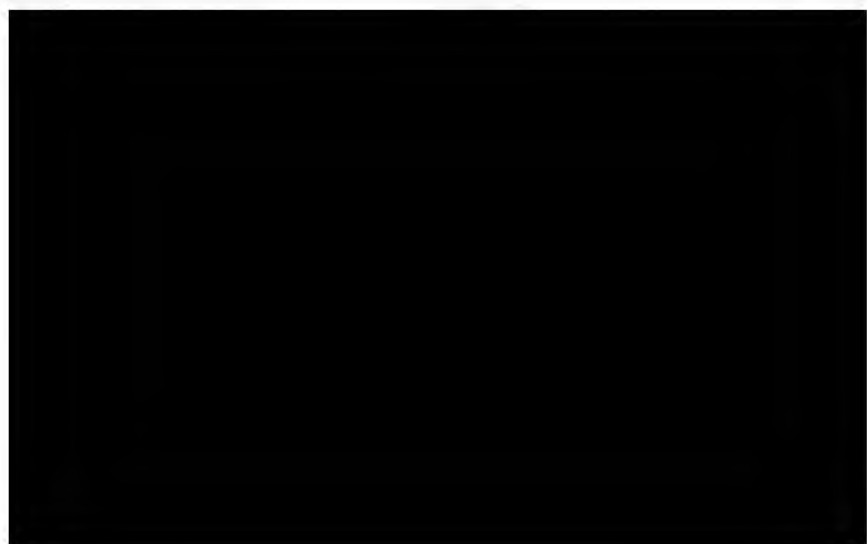
1. CHARACTERISTIC EXPOSURE OF VOLCANIC ASH NEAR BASE OF MONTEREY FORMATION.

At point where Cuyama River enters the Santa Maria Valley. Photograph by Ralph Arnold.



2. UPTURNED AND CONTORTED SEMIFLINTY MONTEREY SHALE.

On Sisquoc River, 5 miles east of Sisquoc. Heavy oil is exuding at a point immediately to the right of the man. Photograph by Ralph Arnold.



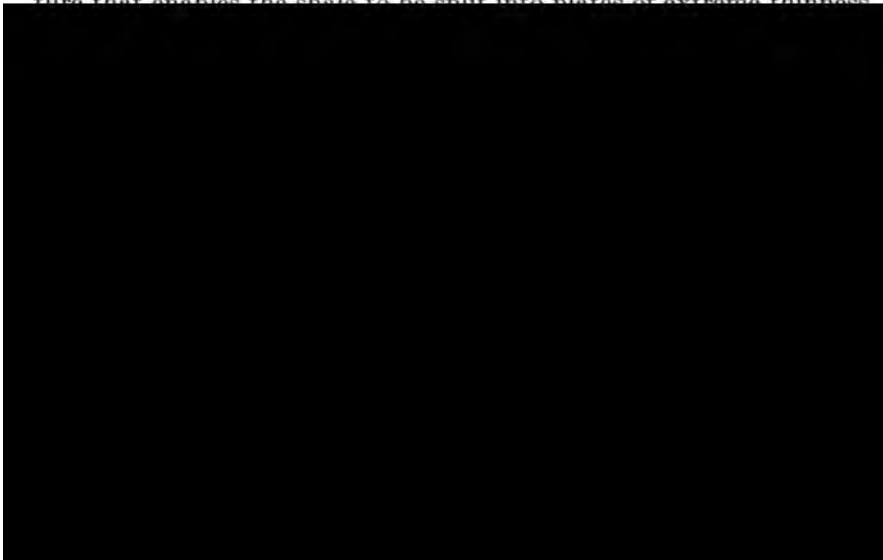
It is in some localities banded with fine white laminae or with bands more translucent than the rest. These bands run parallel with the bedding, and commonly show intricate contortions. The flint fractures conchoidally. From the flint there is every step in the gradation through rocks of less hardness and flinty, compact character to soft white diatomaceous shale. The soft unaltered shale in which the constituent diatom tests are plainly to be seen occurs sparingly, however, in the lower division. A striking example of its occurrence at that horizon can be found at the very base of the Monterey on the San Julian ranch, at the junction of El Jaro and Salsipuedes creeks, where it is pure, soft diatomaceous earth in thick beds, associated with flint and lime and overlying the hard fossiliferous, calcareous conglomerate of the Vaqueros. The specimen of analysis 3 (p. 45) is from this point. The varieties of shale are very numerous, but there is no departure from the general siliceous and calcareous types so peculiar to this formation. There is no common clay shale or slate derived from it, and only very locally is there an appearance of a sandy texture. In the San Rafael Mountains the series has a somewhat different character, especially at the base, where a considerable amount of sandstone, in some places soft and in others quartzitic, is interbedded with the hard calcareous shales. Hard, coarse, yellow and grayish volcanic tuff of acidic nature is interbedded with the Monterey in the vicinity of Cuyama River (see Pl. III, A), and elsewhere the lowest portion of the formation is marked by beds of tuff of local extent. At the east end of the Santa Rita Hills the Vaqueros grades into the Monterey through beds of coarse basic tuff composed of small fragments of glass and crystals of various kinds and of large fragments of pumice. Round boulders or nodules of very fine grained basalt that look like volcanic bombs are included in this tuff.

The series of hard shales of the lower division is commonly impregnated with bituminous material. The limy beds have almost universally a bituminous odor and some of them contain pockets of tarry oil. The same is true of the flint with the difference, however, that the limestone is impregnated with petroleum, owing to its porosity, whereas the oil in the compact flint seems more commonly to be contained along lines of fracture or in cavities. The great mass of the hard, brittle shales has in general a similar odor or is discolored with oil. This hard shale series, especially the lower portion of it, and in places possibly the uppermost sandstone of the formation just below it, contains the principal oil-bearing zones in the developed fields. The fact that this shale is so brittle and fractures when folded has an important bearing on the storing of oil in this portion of the Monterey. The fracturing produces cavities in which the oil can collect while the softer unfractured shales adjacent remain more or less impervious to the oil.

UPPER DIVISION.

The line of division between the lower and upper portions of the Monterey is rather arbitrary, yet if each portion is taken as a whole the lithologic distinction is marked, and the separation is made natural by the areal limitations of the outcrops of one or the other in various places. Where they are in contact a conformity between the two halves of the formation is evident and a gradation occurs from the porcelaneous and flinty shales of the lower part into the light-colored, earthy beds of the upper. Such is the occurrence, for instance, near the north edge of the hills 4 miles west-southwest of the town of Lompoc.

The greater part of the upper division is made up of white or light chocolate-colored diatomaceous shale, usually of light weight and porous, but grading in places into heavier and harder, more compact, brittle, porcelain-like shale. The soft shale is extremely fine grained, rarely being at all gritty. The bedding is characteristically very thin, but where great masses of the soft white shale, which goes by the name of diatomaceous earth, occur, lines of bedding are usually indistinguishable, except here and there on thin projecting laminæ produced by weathering, or on the upper surface of small cavities due to the eating out of less resistant patches. Pl. IV illustrates two characteristic types of the soft unaltered shale. In the upper view it is massive, and bedding planes are almost indistinguishable except for lines brought into relief by weathering and erosion. In the lower view it is slightly more compact and lies in distinct platy layers. Major bedding planes from a fraction of an inch to several inches apart are distinctly apparent, and there is a further laminated structure that enables the shale to be split into plates of extreme thinness.





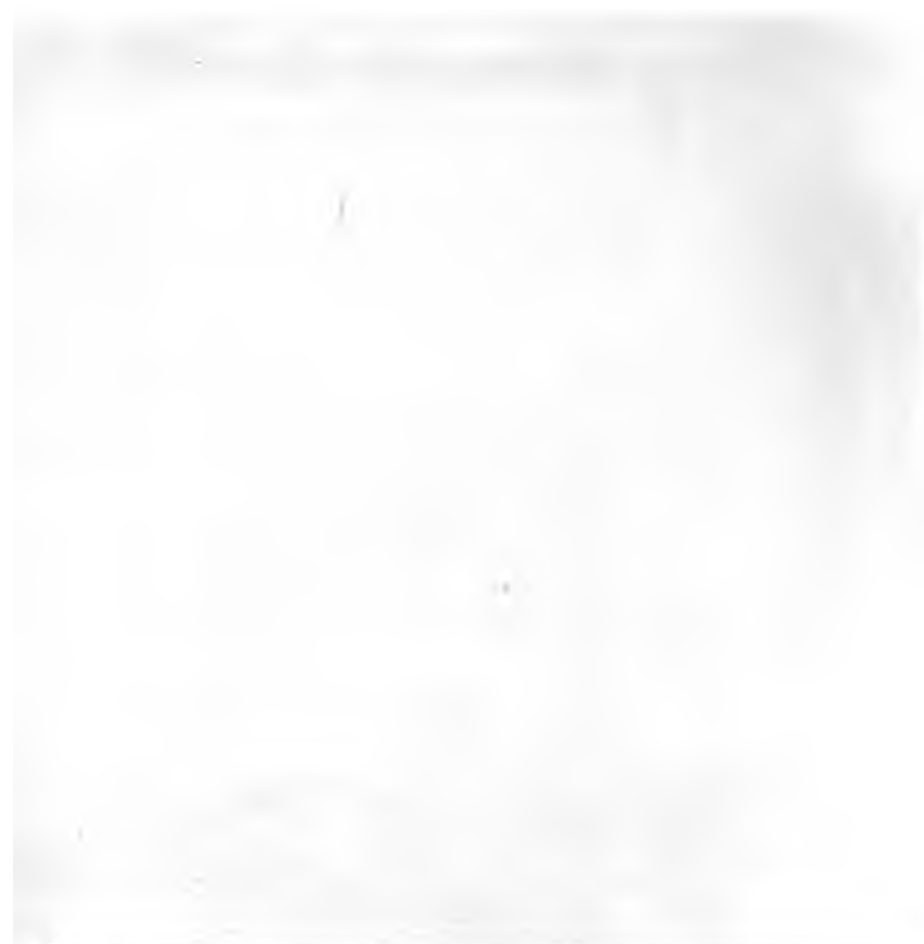
A



B

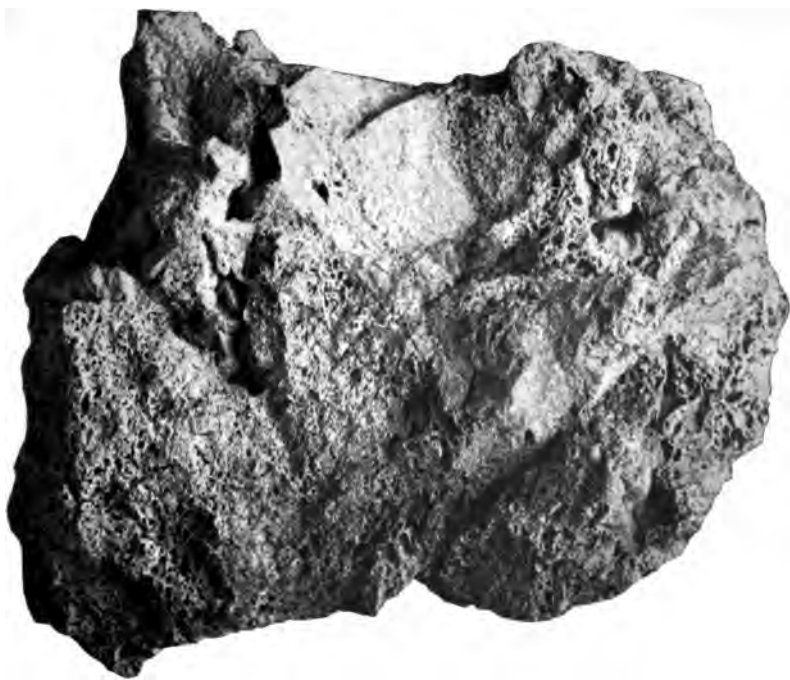
SOFT WHITE DIATOMACEOUS SHALE.

.1. Characteristic exposure north of Casmalia. B. Detail of weathering at Burton Mesa, east of Pine Canyon. Photographs by Ralph Arnold.





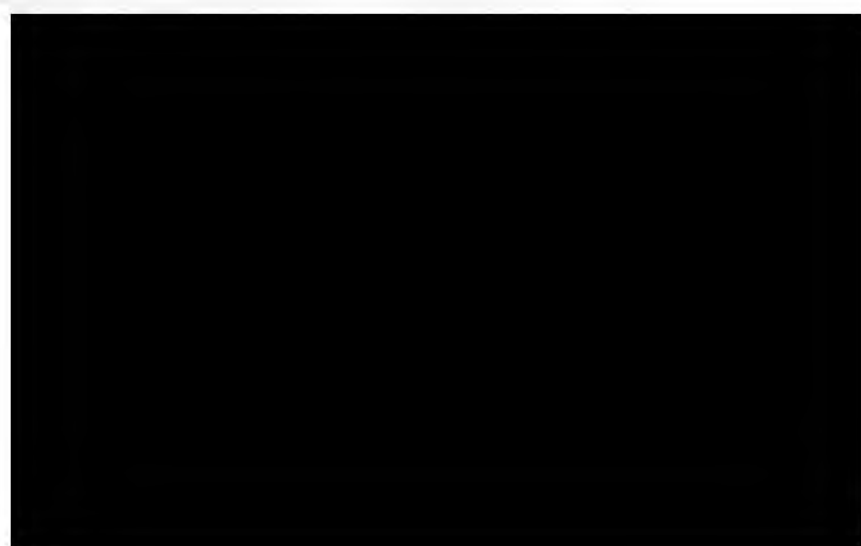
A



B

DIATOMACEOUS SHALE.

A. Typical soft, white, unaltered specimen. B. Red, brittle, and heavy specimen; metamorphosed by the burning of its hydrocarbons.



resemble shale in its thin stratification, the great difference being in the siliceous instead of argillaceous composition. Locally there are beds of clayey nature in the upper division which form a connecting link between the "chalk rock," as the diatomaceous shale is colloquially termed, and common clay shale. Characteristic oval and lenticular yellow concretions of hard lime are commonly included in the shale of the upper division. They range in diameter from a few inches to 2 feet or more. In many places they occur at irregular intervals and of irregular size along a bedding plane, locally displacing the ordinary shale and interrupting the continuity of not merely one bed but many thin beds. They are invariably elongated parallel with the bedding.

Volcanic ash is interbedded with the soft shale of the upper division in the hills immediately south of Lompoc. It is very fine grained, soft, and uncompacted, and probably corresponds in composition to rhyolite. It somewhat resembles the pulverulent diatomaceous earth, but is easily distinguishable by its grayish color and grittiness.

The upper portion of the Monterey, like the lower, is to a large extent impregnated with bituminous material. It is apt almost anywhere in this region to give out a bituminous odor when broken into or to show a brownish discoloration due to the presence of oil. In places the shale, otherwise white, is specked with minute black spots of bitumen. Thin sandy layers occur sparingly interbedded with the shale, and these almost without exception have absorbed considerable oil and have a dark-brown color and strong odor. But these beds of sand are very rare and make up no appreciable proportion of the series.

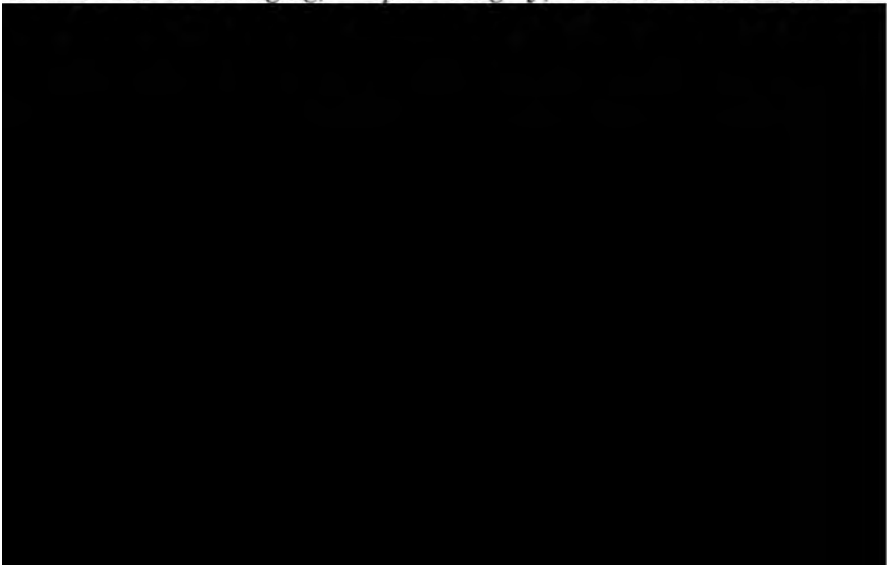
The soft varieties of the Monterey shale are almost invariably alkaline and have a salty taste. They contain an abundance of salts easily soluble in water that form characteristic wooly coatings of efflorescence on the surface of outcrops. This is especially true near the summit of the formation, where a soft claylike gypsum-bearing shale locally marks the contact with the Fernando above. This gypsum is crystallized in plates along seams and bedding planes much like the gypsiferous clay of the Casmalia Hills, which is supposed to be Vaqueros in age. Zones of gypsiferous shale occur also at other places in the upper division of the Monterey, but it is not known whether there are any single horizons at which it is constant. Where the gypsum occurs the shale is usually of more argillaceous character and bears a closer resemblance to ordinary clay shales. The significance of this alkalinity in the Monterey is unknown. The organic shale is considered to be of marine origin in fairly deep water, and owing to the almost complete absence of all but the finest grained detritus the alkalinity can not be considered as proof of shallow-water or brackish-water origin. The salts may have some relation to the chemical changes involved in the production of petroleum.

DIATOMACEOUS EARTH DEPOSITS.^a

The infusorial earth, diatomaceous earth, diatomaceous shale, or tripoli, as the same material is variously called, of which the upper division of the Monterey is chiefly composed, is of fairly pure quality in this region and of considerable economic value, especially as it occurs in inexhaustible quantities close to transportation facilities. The areas of it are extended and the series of strata very thick. Deposits suitable for working occur in the hills immediately south of Lompoc; southwest and west of Lompoc; along the river east of Lompoc; in the northeastern and southeastern portions of Burton Mesa and over the Purisima Hills east of it; over wide areas in the Purisima Hills southwest, south, and southeast of Los Alamos; on the southern flanks of the Santa Rita Hills; $1\frac{1}{2}$ miles north of the Santa Ynez Mission; in smaller amounts near the east edge of the area mapped, a mile north of Santa Ynez River; underlying the San Antonio terrace south of Casmalia; over a wide region southeast, east, and north of Casmalia; on Graciosa Ridge, and in the region extending from the head of Howard Canyon to a point southeast of Sisquoc. The uses to which this material can be put are numerous and the demand for it is increasing.

COMPOSITION OF THE MONTEREY SHALE.**MATERIAL OF SHALE.**

The composition of the Monterey shale is of especial interest. One is able to see on examining the soft unaltered variety with a hand lens, or sometimes even with the naked eye, that it is full of small round dots ranging, to speak roughly, from 0.1 mm. to 1 mm.



the same appearance, as if formed of the same materials, but compacting and crushing seem to have gone a little further so as to obscure the organic remains. Almost all the shale of the upper division of the Monterey contains diatom remains where it has not undergone alteration into the hard varieties. The same is true of the soft shale wherever it occurs in the lower portion of the formation, the most notable example being at the very base of the Monterey on the San Julian ranch east of the junction of Salsipuedes and El Jaro creeks, where it is associated with hard flint and limestone immediately overlying the fossiliferous limestone and conglomerate of the Vaqueros. There the shale is earthy, pure white, and full of diatoms.

When the shale has undergone alteration and hardening into the porcelaneous and flinty varieties the constituent organic remains are usually obscured, but here and there even in these the impressions may be found preserved. Usually an examination under the microscope reveals scattering circular and oval areas, of slightly different composition or character from the surrounding rock, that look as if they might represent the forms of organisms. In speaking of the exposure of Monterey rocks between the mouth of Schumann Canyon and Lions Head on the southern flank of the Casmalia Hills, H. W. Fairbanks says:^a "The basal portion of the series is composed chiefly of clear, flinty rocks, showing abundant remains of organisms visible to the unaided eye." And in speaking of the harder varieties of Monterey shale in general of the Point Sal region he says:^b "When examined with the hand lens much of the rock is seen to be thickly specked with little round dots, averaging, perhaps, a millimeter in diameter. Under the microscope * * * the circular areas did not appear as numerous as in the hand specimen, and were only faintly distinguished by clearer polarization."

Aside from the diatoms the rocks of the Monterey contain remains of minute Foraminifera, which have calcareous frames, and Radiolaria, which secrete silica to form their tests. The latter are present sparingly. The common siliceous shale contains very little lime and no Foraminifera have been found in it in this district, although they have been reported from the typical Monterey shale elsewhere. R. M. Bagg^c found 66 species belonging to 17 genera in chocolate-colored, soft, fine-grained shale of the same formation near Asuncion, San Luis Obispo County. J. C. Branner in the introduction to Bagg's paper, describes the shale as follows: "The shale proper also varies; at some places it is flinty, at others it is somewhat sandy, and at still others it is soft and chocolate-colored, and contains an abundance of well-preserved Foraminifera. * * * The bulk of

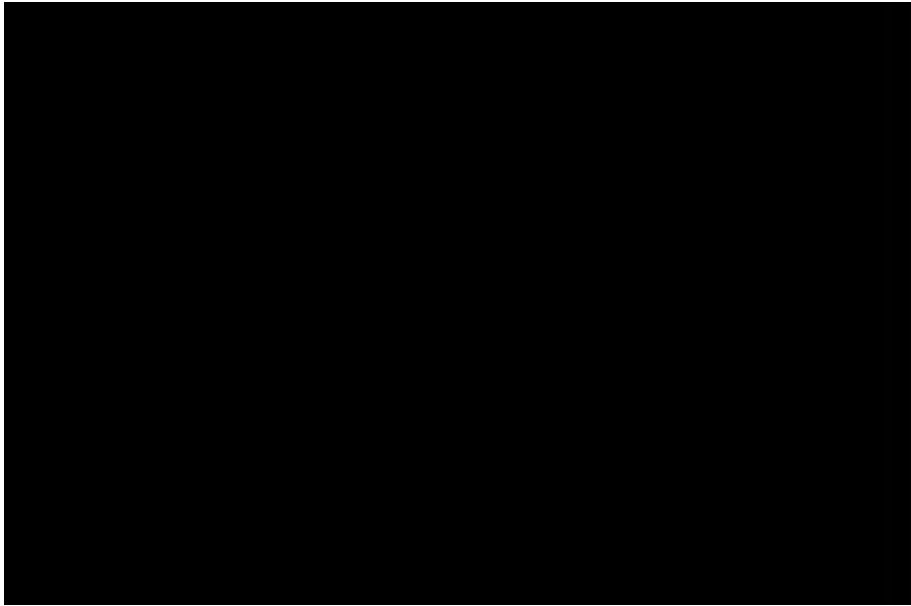
^a *Geology of Point Sal*: Bull. Dept. Geology, Univ. California, vol. 2, No. 1, 1896, p. 9.

^b *Op. cit.*, p. 10.

^c *Miocene Foraminifera from the Monterey shale, California*: Bull. U. S. Geol. Survey No. 208, 1906.

this shale is made of diatom skeletons. * * * Even when the rocks are flinty they often contain good impressions of Foraminifera." Foraminifera occur in the partially calcareous shales of the Santa Maria district, and in places the limestone is full of them. In some specimens they are perfectly preserved and various kinds may be easily seen with the unaided eye. In other places the limestone shows no trace of organisms; but it is the opinion of the writers that they have been present in such places and have lost their shape, and that foraminiferal skeletons account for a large part of all the Monterey limestone and for the calcareous portion of the limy shales. H. W. Fairbanks says in his paper quoted on page — that the limestone of the Point Sal region "appears to be formed almost exclusively of minute organisms."

Specimens representing different varieties of the Monterey shale and flint were sent to F. J. Keeley, of the Philadelphia Academy of Natural Sciences, who very kindly made examinations of them and reported regarding their diatom contents. (See Pls. XIX and XX.) He found diatoms plentiful in the unaltered earthy shale and less common in the more compact shale and in the less pure, either gritty or argillaceous shale. Sponge spicules were common in all the samples, and in those last mentioned they were more abundant than diatoms. No examination was made of the indurated varieties. Mr. Keeley was unable to make more than a hasty examination, but on request he estimated roughly that the purest material contained from 5 to 10 per cent of diatoms and that the soft shale in which fewer could be seen contained possibly 1 per cent. He found a few Radiolaria but no Foraminifera in the pure siliceous shale, diatoms and next to them



Mr. Boyer says: "The deposit consists almost entirely of *C. marginatus* and *C. robustus* of various sizes and often without rims. It is impossible, in certain cases, to distinguish between these two forms. The variety *intermedia* is between the two and was created by Rattray."

The second slide was made from soft shale of the uppermost portion of the Monterey, from the Pinal property on the east side of Pine Canyon, on the north flank of Graciosa Ridge. The following diatoms were found:

Coscinodiscus oculus iridis Ehrenberg (abundant) (Pl. XI, fig. XIX).

Coscinodiscus marginatus Ehrenberg.

Coscinodiscus marginatus var. *intermedia* Rattray.

Coscinodiscus robustus Grev. (Pl. XX, fig. 4).

Coscinodiscus radiatus Ehrenberg.

Coscinodiscus obscurus A. S. (Pl. XX, fig. 2).

Coscinodiscus nodulifer Janisch.

Coscinodiscus heteroporus Ehrenberg.

Coscinodiscus subtilis Ehrenberg (Pl. XX, fig. 3).

Actinoptychus undulatus Ehrenberg (rare) (Pl. XX, fig. 1a).

Arachnodiscus ehrenbergii var. *californica* (fragment).

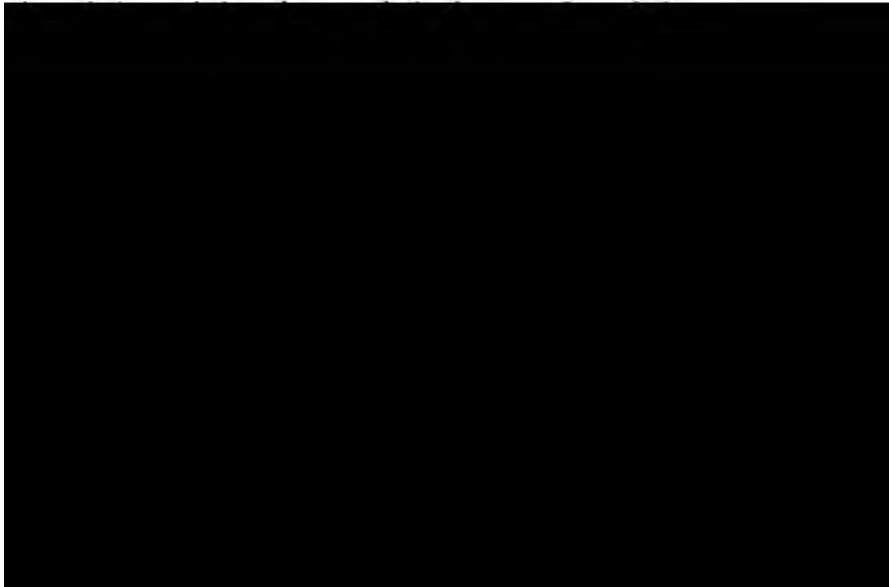
Lithodesmium cornigerum Brun. (Pl. XX, fig. 1b).

According to Mr. Boyer this second sample consists chiefly of fragments of *Coscinodiscus oculus iridis* Ehrenberg, which is a larger and more delicate form than the one predominating in the first, and both he and Mr. Keeley comment on the peculiar absence of it there. The difference in the fauna in these different localities is of interest, inasmuch as the deposit represented by the first slide was at the base of the Monterey and that represented by the second near its summit.

Besides the small organisms that have been described as forming a portion of the shale material, and the less abundant organic remains mentioned on pages 42-43, the deposits of Monterey age contain a considerable percentage of fine siliceous and aluminous matter, probably of detrital origin, in the shape of exceedingly minute elastic grains. The chemical analyses of specimens from different localities show a large percentage of alumina, the presence of which is probably the result of fine argillaceous silt settling on the sea bottom to aid in the formation of the shale. The origin of the silica is more in doubt. There is no question of the presence of a large amount of siliceous diatom skeleton material, and the many fine-rounded and angular particles of quartz revealed by the polarizing microscope in the unaltered shale indicate that the sediments derived from shore areas carried quartz grains also, but there is no proof as to which of these sources supplied the bulk of the silica, of which the shale is mostly composed. Besides the recognizable diatom remains it is impossible to tell how much of the shale is composed of similar skeletons that have been crushed beyond any semblance of their original form. Comparatively few forms are perfectly preserved, most of

those observed under the microscope being only fragments, and this makes it probable that others are still more fragmentary and in a state of complete demolition. The likelihood, therefore, is that a greater proportion of the pure shale than 5 to 10 per cent, as roughly estimated by Mr. Keeley on the basis of visible forms, is composed of silica derived from diatoms. Radiolaria, which are scattered through the shale sparingly, have contributed somewhat to the organic silica. Whatever conclusion one should come to would apply to almost all of the soft unaltered shale of the siliceous type in the Monterey of the Santa Maria district, as this type is fairly constant. Locally it is varied by an increased proportion of argillaceous material, causing a greater similarity in appearance to ordinary clay shale, or by the presence of lime; but diatoms are visible in practically all of it and the general conditions of deposition seem to have been the same throughout. The conclusion is reached elsewhere (p. 47) that the same probable origin may be assigned to all the siliceous shales of the Monterey, whether hard or soft—or, in other words, to by far the greater part of the formation.

The list of organic constituents of the shale is by no means exhausted by the small organisms of low order so far mentioned. Another important source of silica lies in the abundant sponge spicules, which are only second in number to the diatoms and which are scattered with remarkable persistency throughout the shale. In the slightly gritty beds of soft shale, which occur sparingly, these spicules even predominate over the diatoms, being possibly the cause of the grittiness. They seem also to be less easily obliterated than the fragile diatom shells and to have been preserved in places where slight alter-



less purely siliceous varieties, are usually full of small brown scales, spines, and fragments or impressions of nondescript shape which are of organic origin but which can not be recognized as belonging to any particular forms. Here and there, also, large bones are embedded in the deposits. They seem to be those of whales or other large marine vertebrates.

Taken as a whole, the Monterey shale may well be called an organic formation. The practically complete absence of coarse sediments derived from erosion and the abundance of fossil organisms, especially of siliceous skeletons, make it different both in appearance and composition from any other known formation of comparable thickness. The unaltered siliceous shale most nearly resembles chalk, but it contains only a small proportion of lime. Whether or not the organic remains compose more than half or as much as half of the deposit can not be stated.

MICROSCOPIC APPEARANCE.

Under the polarizing microscope little can be made out regarding the structure of the main mass of the soft shale and compact white shale. The groundmass seems to be made up of amorphous colloidal silica surrounding minute grains which are both crystalline and amorphous, but the character of which can not be recognized. Embedded in this are numerous imperfectly angular or more rarely partially rounded crystal particles, probably of quartz. Many of the latter look as if they were due to secondary development rather than originating as clastic grains.

In the more flinty varieties the rock appears to have undergone partial and local crystallization of the silica throughout its mass. In the flint, in which there are alternating, usually crumpled bands of opaque light-colored flint and clear amber-colored or black flint, the opaque bands are composed mainly of amorphous material like that of the softer shale, but in a much more compact state, and the translucent bands are mainly crystalline aggregates. The opaque bands include crystalline particles and, locally, patches of crystal grains like those of the clear flint, and they are included longitudinally by intermittent bands of the clear flint. Furthermore, they are in many specimens of a patchy appearance, parts being less amorphous than others. The bands of the clear flint are composed chiefly of small grains of crystalline quartz, and these are surrounded by a finer grained aggregate of crystalline and amorphous particles. The quartz grains have neither the rounded outlines of waterworn grains nor angular crystalline outlines, but are branching, and appear more like growths. Angular patches of the amorphous silica, many of them showing signs of

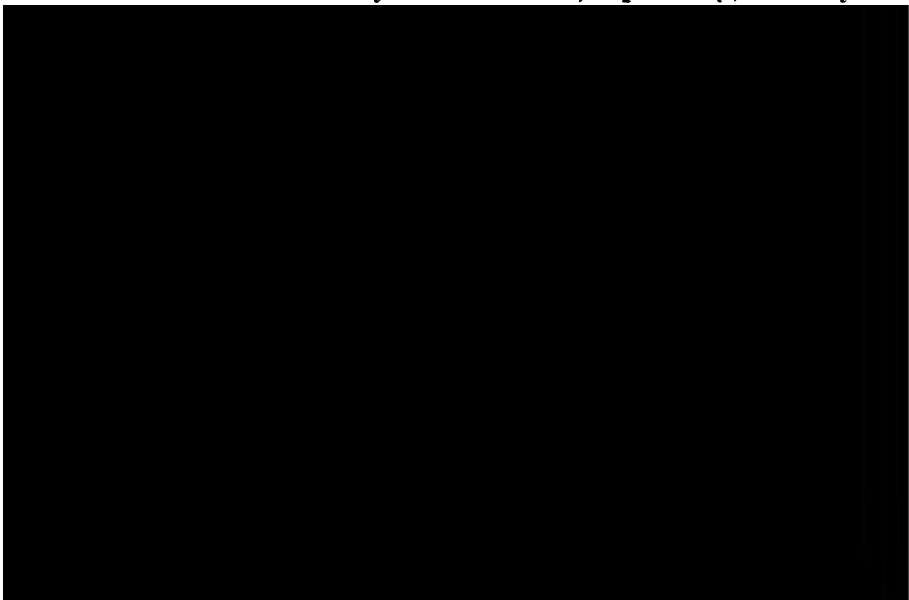
incipient crystallization, are included in the clear bands, giving a brecciated appearance. The bands are parallel with the bedding planes. They are commonly followed and more rarely crossed by veins of quartz crystals.

The limestone is made up of granules of crystalline calcite, or calcite showing the beginnings of crystallization. Included in this extremely fine grained, uniform groundmass are larger but yet very small, irregular grains of crystalline calcite, and in places long spicules of the same. In some specimens the granules are more minute than in others and the included larger grains are fewer. In still others, crystallization has entirely altered portions into patches of large, intergrown crystals, leaving angular, unchanged patches sharply marked off, and thus giving an appearance like that of a breccia. The flinty calcareous shale has a minute granular texture, quartz grains both crystalline and semicrystalline being associated with those of calcite. The rock usually has light and dark bands parallel with the bedding, the light bands containing more quartz and having the calcite granules less close together than the darker bands.

CHEMICAL COMPOSITION.

The subjoined table comprises analyses of different specimens and varieties of Monterey shale from the Santa Maria district, with one (No. 5) here included for comparison, of a sample of white bituminous shale from the type locality of the formation at Monterey, farther north on the California coast.

The first three represent typical examples of the unaltered diatomaceous shale of the Monterey. Nos. 3 and 2; respectively, are analy-



Analyses of Monterey shale.

	Diatomaceous shale.					Flinty shale.					Limestone.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
SiO ₂	65.62	72.50	83.19	80.59	86.80	92.88	86.92	92.37	97.02	98.1	.....
Al ₂ O ₃		11.71			2.32		4.27	2.46		Not det.	.....
Fe ₂ O ₃ (total iron)....		2.35			1.28					Not det.	.....
CaO.....		.32			1.43		1.60	1.70			27.86
MgO.....		.83			Trace		Trace				16.64
Alkalies (Na ₂ O, K ₂ O).....		1.88			3.58		2.48				
Ignition.....	11.00	9.54			4.80		5.13	2.74+CO ₂			
		99.13			100.39		100.40	99.27			

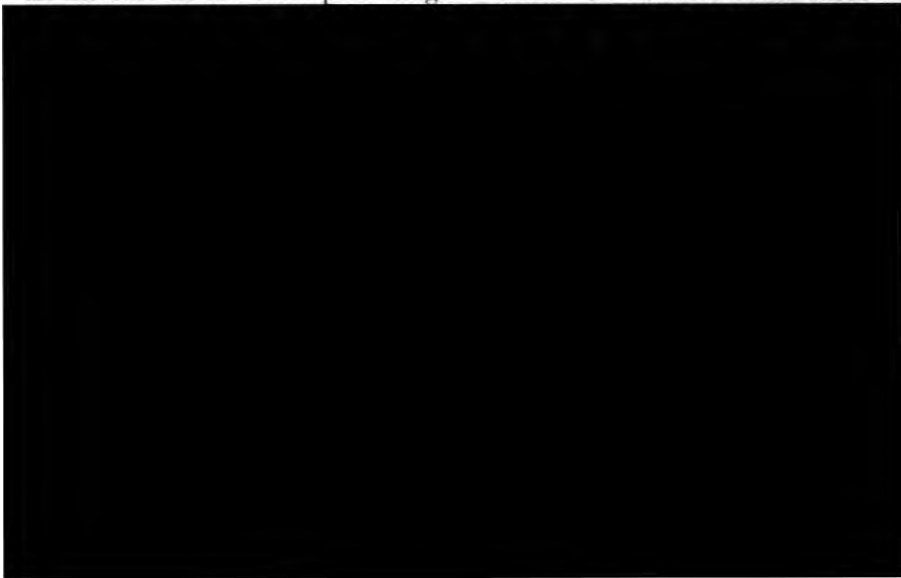
1. Soft, white diatomaceous shale; Purisima Hills, 3½ miles southwest of Harris, Santa Barbara County, Cal. Analyst, W. T. Schaller, 1907.
2. Soft, white diatomaceous shale; Graciosa Ridge, 3 miles southeast of Orcutt, Santa Barbara County, Cal. Analyst, W. T. Schaller, 1907. Approximate analysis.
3. Soft, white diatomaceous shale; San Julian ranch, at junction of El Jaro and Salsipuedes creeks, Santa Barbara County, Cal. Analyst, E. C. Sullivan, 1907.
4. Soft, white diatomaceous shale; San Antonio terrace, 2 miles south of Casmalia, Santa Barbara County, Cal. Analyst, E. C. Sullivan, 1907.
5. White shale; Monterey, Monterey County, Cal. Lawson, A. C., and Posada, J. de la C., Bull. Dept. Geology, Univ. California, vol. 1, 1893, p. 25. Specific gravity, 1.8-2.1.
6. Gray, glassy porcelain shale; from same hand specimen as No. 4. Analyst, E. C. Sullivan, 1907.
7. White porcelain shale; region of Point Sal, Santa Barbara County, Cal. Analyst, H. W. Fairbanks, Bull. Dept. Geology, Univ. California, vol. 2, No. 1, 1896, p. 12.
8. Opaque flint; Point Sal, Santa Barbara County, Cal. Analyst, H. W. Fairbanks, loc. cit.
9. Hard, black, clear flint; 1½ miles west of Zaca, Santa Barbara County, Cal. Analyst, E. C. Sullivan, 1907.
10. Hard, black, clear flint; Point Sal, Santa Barbara County, Cal. Analyst, H. W. Fairbanks, loc. cit.
11. Bituminous limestone; Redrock Mountain, northeast of Lompoc, Santa Barbara County, Cal. Analyst, George Steiger, 1907.

ALTERATION.

The differences in character and composition between the soft and hard varieties of the Monterey shale have been brought out in the foregoing discussion. The question arises, To what are these differences due? It is difficult to give a decisive answer. The main differences in the gradations from the soft to the hard shales lie in the siliceousness, compactness, hardness, and degree of crystallization. Taken as a whole the lower division is made up largely of hard shale and the upper of soft shale, but gradations from one variety to another within an extremely small space occur in both divisions. In some places a thick series of beds of similar character is marked off from a series of different character. Elsewhere a variation occurs bed by bed, or, in still other places, a single bed or lens of shale of one variety is included within another kind. The softer varieties contain at many points small lenses of hard, brittle, or semiflinty shale elongated parallel with the bedding, or strata in which lenses are strung along at irregular intervals, or single small beds composed entirely of harder material. In such occurrences there seems to be a gradation from one variety to the other, and the outlines of the hard layers are not regular or very definite. For example, the diatom-bearing shale of chemical analysis No. 4 and the glassy

opaline rock of analysis No. 6 were samples taken from the same hand specimen within 1 inch of each other. The mass of the deposit from which the specimen came was soft white shale belonging high in the formation and contained a rough layer, a few inches thick, of the harder material between two beds of the soft rock.

The soft shale has been described in the preceding pages as "unaltered," and in referring to the harder varieties different degrees of "alteration" have been mentioned, for the reason that the best explanation of the origin of the harder rocks appears to be that they are products of metamorphism of the soft variety. It is believed that the soft white and chocolate-colored organic shale represents the original state of the beds of the whole formation, and that a process of silicification and crystallization has caused the changes, this process having been aided possibly by structural disturbances and pressure. The beds of soft shale are usually found in attitudes only gently disturbed, whereas the harder shale is most commonly much folded and is invariably the component rock of folds where the forces have been especially intense. This fact may throw light on the problem of the alteration of the shale, and yet it may be simply the outcome of the removal of the softer portion of the formation in the regions of greatest uplift and disturbance. The chief agent in causing the change was probably infiltrating water carrying silica in solution. In some places the process may have been simply or largely infiltration in the extremely porous original shale and deposition of silica in the interspaces, thus giving rise to hardened and compacted irregular granular aggregates of the original amorphous silica and the new crystalline silica combined, the result being an increase in the total percentage of silica. In more extreme cases





.1. CHARACTERISTIC EXPOSURE OF FERNANDO GRAVEL.

Second ridge east of Figueroa Creek, 7 miles northeast of Los Olivos. Photograph by Ralph Arnold.



B. SHARP DOUBLE FOLD IN MONTEREY SHALE.

Looking east from point northwest of Zaca Lake; Zaca Peak in distance. Photograph by Ralph Arnold.

100

100

rial might have been, and the more or less completely crystalline character of the harder shales shows that metamorphism has taken place. The most plausible theory, therefore, is that the Monterey shale as originally laid down was fairly constant in character and that it has undergone alteration extensively, as well as very locally, through the agency of siliceous waters, the older portions of the formation, and possibly the more disturbed portions, having been most generally subjected to the change. The limestone has in places been altered after a fashion somewhat similar to that of the siliceous shales, being changed to marble, probably as the result of solution and redeposition.

The Monterey rocks likewise show the result of contact metamorphism to a very local extent in the vicinity of the diabase intrusions. The process seems to have been largely one of consolidation through baking. A limestone specimen obtained near the diabase intrusion north of Zaca Peak, in the San Rafael Mountains, gives an excellent illustration of shearing. The calcite crystals have all been arranged parallel and greatly elongated, so as to give the rock a schistose structure.

STRUCTURE AND THICKNESS.

The Monterey has nowhere been left undisturbed. In places it has been but gently folded. Pls. IV (p. 36), VIII, *B* (p. 78), and IX (p. 80) show examples of moderate tilting. But at other places, as at that pictured in Pl. VI, *B* (p. 46), it has been thrown into folds so sharp and closely spaced that the succession of the beds and thickness of the series are difficult to make out. The details of its structure are discussed under the heading "Structure" (pp. 76-78). The thickness of the whole series is at least 5,200 feet. Each of the two divisions comprises a maximum known thickness of 2,600 feet. No single complete section of the whole could be obtained.

EVIDENCE OF AGE.

A paucity of recognizable molluscan fossils is one of the prominent characteristics of the Monterey in this region, as in most others in the Coast Ranges where it outcrops. Moreover, the other fossils that it contains are of little value in indicating its age. Its position in the geologic column is determined by the lower Miocene fossils found just below its base in the Vaqueros and by the upper Miocene fossils found at or near the base of the Fernando formation, which lies unconformably above it.

The following two species of mollusks occur in the Monterey diatomaceous shale on the road just above the Pinal Oil Company's office, southeast of Orcutt: *Arca* aff. *trilineata* Conrad, *Phacoides* aff. *acutilineatus* Conrad.

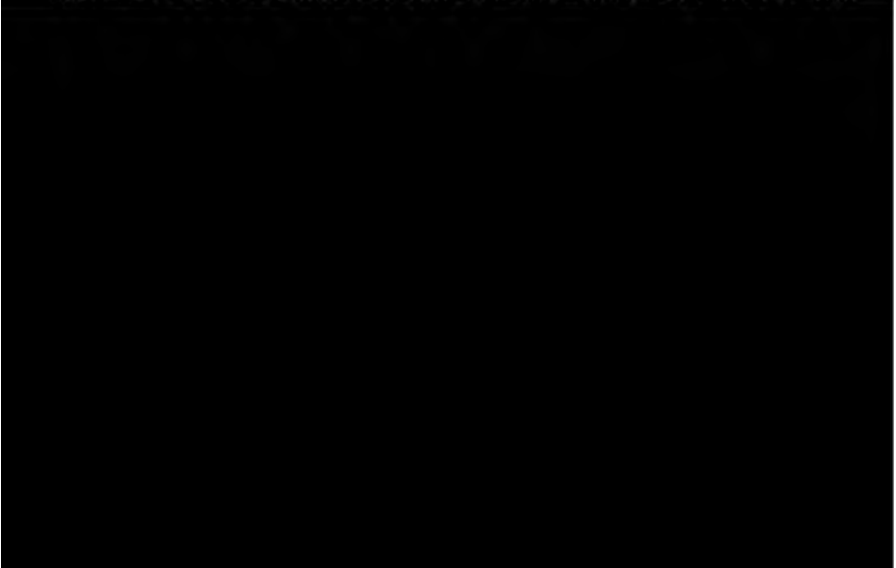
METAMORPHISM OF THE SHALE BY COMBUSTION.

At many different places in the Santa Maria district and elsewhere the oil-bearing shale has been burnt to a pink or deep brick-red color, or turned into a hard vesicular rock like scoriaceous lava, as shown in Pl. V, *B*, p. 36. This metamorphism is due to the combustion of the hydrocarbon content. Though the combustion is usually local in its effects, the number and wide distribution of the occurrences of burnt shale lend importance to the phenomenon. Such altered shale is of some value as indicating where the rock has been bituminous and where the conditions have favored the occurrence of seepages.

LOCALITIES WHERE THE SHALE IS AT PRESENT BURNING.

A number of localities have been observed at which combustion is at present or has been in recent years in progress within the Monterey shale. One of these is on the north side of Graciosa Ridge, south of the Santa Maria Valley, near the Rice ranch oil well No. 1. When this locality was visited by the writers early in the autumn of 1906, a fire was burning underground in the shale, causing a smoke of disagreeable odor to issue from the surface and making the ground hot over an area of many square yards. Oil was oozing up at various points near by, and the ground was heated in the neighborhood of all these seepages. The holes from which vapor issued were coated with delicate crystals of sulphur. At the point where the burning was actually going on and all about in the vicinity, for a distance of several hundred feet in some directions, the shale was altered to a bright-red color, or baked almost to the hardness of compact igneous rock, or rendered vesicular like lava.

There are many localities where this process is going on at the present time.



of solfataras and have given rise to the opinion that volcanic activity is present in this region. This so-called "Rincon volcano" existed before 1855, being referred to in the Pacific Railroad reports; this shows that the burning has continued a long time.

TYPICAL OCCURRENCES OF BURNT SHALE.

Outcrops of burnt shale occur in eight or ten localities in the Santa Maria district. The best examples are at various places along the ridge of the Casmalia Hills from a point south of Schumann to Waldorf; on the north and south sides of Graciosa Ridge; and on Redrock Mountain 4 miles southeast of Los Alamos. In each of these regions every stage of alteration is exhibited, from the slightly discolored shale to hard slaglike rocks of varying shades of red and black. The area of altered shale in the different localities ranges from about a hundred square feet to a half a square mile or more, as at Redrock Mountain. In each the burnt rock is surrounded by unaltered, usually soft, white, diatomaceous shales which in most places show the planes of stratification. At no point observed was a sign of stratification left in the baked shale. In every occurrence the shales in the neighborhood are bituminous and asphalt deposits are usually adjacent.

The largest area of altered shale is on the summit and surrounding ridges of Redrock Mountain. This is the highest of the hills in the basin region between the San Rafael and Santa Ynez mountains, being 1,968 feet above the sea; the height of most of the summits in the vicinity is from 1,000 to 1,500 feet. Redrock Mountain seems to owe its prominence, at least in part, to the metamorphosed shale that forms its summit. Likewise, in the 800-foot hill on the southeast side of Schumann Pass, the capping of this same character, resembling volcanic rock, seems to have caused the topographic relief. The metamorphism in these localities probably took place a long time ago. At Redrock Mountain great deposits of asphalt are in places in contact with the altered shale, and there is a large area of shale impregnated with bitumen.

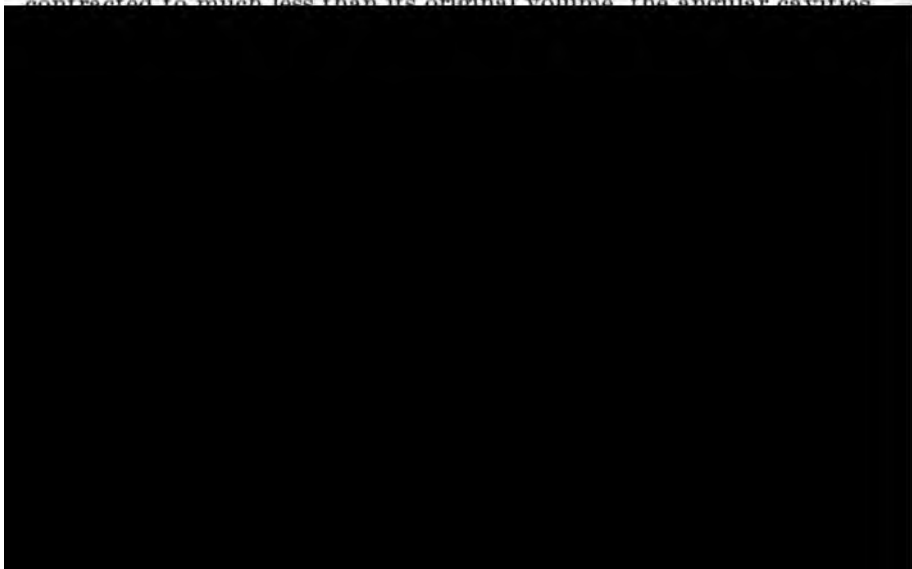
DEPTH TO WHICH ALTERATION HAS EXTENDED.

The depth to which alteration has extended below the surface in these occurrences is difficult to determine. A cliff of burnt shale 50 to 100 feet high is exposed $4\frac{1}{2}$ miles due south of Guadalupe, and the difference of elevation of points in the Redrock Mountain neighborhood where the altered rock outcrops amounts to several hundred feet. That such metamorphism of the shale has not been solely a surface phenomenon is shown by the fact that burnt shale has been found at considerable depths in drilling. Mr. Orcutt, of the Union Oil Company, exhibited samples of red shale, coming from depths of 950

to 1,040 feet below the surface in Hill well No. 1, in the Lompoc field, which are identical in appearance and texture with the burnt shale elsewhere. Traces of petroleum were associated with the upper stratum of burnt shale in this well. In numerous other wells in the Santa Maria field red shale, doubtless burnt, was found at depths ranging between 90 and 330 feet below the surface. The hardening consequent on the burning has in some places rendered the rock difficult to pierce with the drill.

LITHOLOGIC CHARACTER OF BURNT SHALE.

The burnt shale exhibits all stages of change from a slight induration and discoloration, due, probably, to oxidation of iron, to an extreme hardening and partial fusion. Where slightly altered, the normal white shale assumes a light-pink color. From this stage it passes through various shades of rose and brick-red and deepens in color to a reddish, bluish, or greenish black, or even a true black. In the advanced stages of change it becomes a rough, brittle, reddish, porous slag, like vesicular lava, or a very hard, compact, dark, and dull-colored rock, looking something like a compact igneous rock. An example of partly vesicular and partly compact burnt shale is shown in Pl. V, *B* (p. 36). Burnt shale is not crystalline, but the texture is so variable as to give a patchy appearance to surfaces. In one place it may be compact and black, nearly full of irregular cavities, surrounded by patches of different colors; in another, vesicular and reddish. Whereas the weight of the original shale is slight, the lighter varieties having a specific gravity less than that of water, the excessively burnt shale is very heavy. The material has evidently contracted to much less than its original volume, the angular cavities



The likeness of varieties of the burnt shale to volcanic rocks is indicated by the fact that Thomas Antisell, in his account of the geology of the Coast Ranges in the Pacific Railroad reports,^a describes "scoriaceous" and "amygdaloidal lava," "whitish-gray, hard trachytic rock," "volcanic," and "igneous rocks" in the region of Santa Ynez River, evidently having reference to the burnt shale. He considered these rocks to be eruptive masses, forming the oldest and axial rocks of the hill ranges, whereas they are part of the Monterey shale, which overlies the basement formation. He regarded the associated diatomaceous shales in some places, although not in others, as "magnesian" and "tremolite" rocks of igneous origin, and refers to the places where the shale is burning as examples of present volcanic activity.

CAUSE OF THE ALTERATION.

There can be little doubt that the burnt condition of the shale is in all places the result of heat produced by combustion of its hydrocarbon content. The phenomenon is confined to the Monterey shale, which is the source of a large part of the California petroleum, and to those regions in which this formation is extremely bituminous. The shale in many such places is impregnated with petroleum and the cracks partially filled with it. The areas of altered shale are almost invariably situated in the vicinity of oil seepages, which usually denote a fractured condition of the rocks such as would allow fire to spread and be supported. The observance of fires actually in progress in the shale and the changes that have taken place in the neighboring rocks—changes in every way similar to those in localities where no fire exists at present—give the best clues to the manner in which the shale has been baked in other places. It is difficult to conceive another source of heat sufficient to cause local baking of the shale in otherwise unaltered strata at a depth of 1,000 feet below the surface in such a case as has been mentioned. Probably there, as on the surface, it was due to ignition of bituminous material. It is probable that fire started in the petroliferous shale at the surface and threaded its way downward along cracks partially filled with bitumen. The failure to smother the fire in the shale on Graciosa Ridge, previously noted, indicates that such fires are able to survive with a small air supply. On the other hand, if the above theory is correct, it indicates that a considerable amount of oxygen may be present in the rocks at such a depth.

In this connection it may be mentioned that the temperature in a well near the one in which the burnt shale was found was 152° F., at a depth of 3,600 feet. The cause of ignition may be kindled fires, lightning, or the spontaneous combustion of the hydrocarbons or

^a *Explorations and surveys for the Pacific Railroad*, vol. 7, 1857, pp. 65-72.

surface vegetation. Many of the recent cases of burning are directly traceable to the first cause, but for those which may have taken place before the advent of man either the second or third cause will have to be invoked.

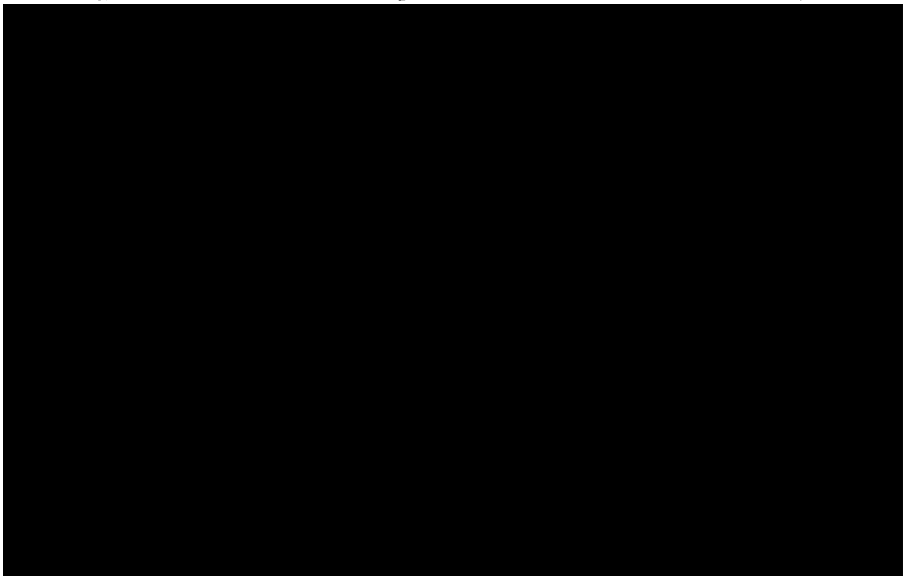
RANGE IN TIME OF THE PHENOMENON.

As already mentioned, the marked influence of the hardened shale on the topography in certain places indicates that it originated in those places a long time ago. The age of some of the burnt shale is further shown by the presence of numerous fragments of it at a depth of at least 10 feet below the surface in horizontal beds of Pleistocene age. These beds consist of sand, clay, and rough gravel, and form the low hills between Guadalupe Lake and the high hills to the west. The fragments of shale are little worn and evidently of local derivation, having possibly come from the cliffs already mentioned south of Guadalupe. The fact that the Monterey shale has undergone this kind of baking in Pleistocene as well as in recent time indicates further that the accumulation of the oil and its dissemination in the surface rocks took place, or were taking place, before the latest orogenic movements in this coastal region.

FERNANDO FORMATION (MIOCENE-PLIOCENE-PLEISTOCENE).

GENERAL STATEMENT.

The name Fernando was first applied by Homer Hamlin to a series of rocks overlying the Monterey in the San Fernando Valley, Los Angeles County. The formation has since been recognized by Eldridge and Arnold^a in the region of the Puente Hills, Los Angeles,



Barbara County, where it was deposited in the old basin between the Santa Ynez and San Rafael ranges. It covers up the Monterey over the greater part of the basin, and as its structure in most places there conforms approximately to that of the Monterey, it is a fairly good key to the folding that has taken place in this underlying formation. The relation between the Monterey and Fernando is of a somewhat perplexing nature. An unconformity in dip between the two was not to be definitely made out on examination of the exposed contact in any part of the central basin, because of the fact that the Monterey and Fernando were subjected practically to the same movements over a large part of the region. Lithologic similarity of parts of the Fernando to the Monterey is also an obstacle to their differentiation. But pebbles of Monterey shale and flint, showing here and there pholas borings and giving evidence of marine deposition, are abundant in the Fernando. In fact, the greater part of the coarse detrital material of the Fernando conglomerate is derived from the Monterey, proving that its period of deposition was one of erosion in the previously deposited shale, that it followed the uplift above sea level of a portion of the Monterey, and that it was subsequent to the formation of the flint in that shale series. The importance of the break between the two is indicated by the change in character of the deposits from organic, probably deep-water sediments almost free from erosional débris to sandy and gravelly deposits derived from the wearing away of hard land areas. This change was hardly as marked as that occurring in the reverse order at the close of Vaqueros time, although it accompanied what was probably a greater time and structural break. The apparent structural conformity between the Monterey and Fernando at most places within the basin region is probably due to the previously almost undisturbed attitude of the shale upon which the Fernando was laid down and the subsequent disturbance of both formations at the same time. But remnants of the Fernando left around the border exhibit less conformity with the underlying Monterey, owing doubtless to the fact that the shale of the latter was upheaved around the edges of the basin to form the mountains bordering it during the period intervening between the close of Monterey time and the beginning of deposition of the Fernando.

The chief importance of the Fernando in connection with studies of this oil field is derived from the facts that it hides the oil-bearing formation over a wide area; that it affords through its structure, however, a clue to the structure of the underlying Monterey; and that it acts as a reservoir for oil (Arroyo Grande field) and as a receptacle for escaping bituminous material. In the last-mentioned way it gives origin to asphalt deposits of economic value and to cappings of hard asphalt that may be of significance as an aid in the retention of the oil *within the Monterey*.

LITHOLOGIC CHARACTER.

This formation is mapped as a unit, although it certainly represents a long period during which sedimentation, continuous in the region as a whole, was locally intermittent and carried on under differing conditions, owing to the differential elevations to which the region was subjected. The stratum resting upon the Monterey in one place is apt to be absent in another, where an overlap of one or another stratum may occur. The lowest recognized Fernando rocks occur south of Sisquoc, where the Monterey is overlain by a bed of brecciated and waterworn shale derived from it and cemented by argillaceous sand, above which lies about 200 feet of fine sand, succeeded by a 50-foot layer of diatomaceous shale that is indistinguishable from that of the Monterey. Above this shale the series grades up through about 600 feet of fine white and yellow sand and coarse sand, until a bed of conglomerate is reached. At other places, as south of Waldorf and south of Harris, the lowest stratum found at Sisquoc is either wanting or of minor importance, and beds of diatomaceous shale lie conformably over the Monterey shale, making the dividing line very hard to find. West of Waldorf the contact is marked for miles by a bed of brecciated Monterey shale of coarse and fine fragments, in places cemented into a hard amalgam by a paste of bituminous material. Here the overlying beds are made up of fine shale and sand and pebbly sandstone, which, though actually separated by an important unconformity from the Monterey, as indicated by the brecciated zone and the abundance of pebbles of that formation in them, are conformable in dip with the underlying beds. A still younger series of fossiliferous shale and sand marks



It would be difficult to work out the limits of the area that this remnant covers. In all probability it is very small, and it has not been shown on the map. This shale here forms the base of the Fernando. A pebbly layer with constituent well-worn pebbles of Monterey shale embedded in sand has aided in the accumulation of asphalt on the summit of the ridge near by, where it probably marks the basal line of the Fernando formation.

Above the soft diatomaceous or gritty shale and fine white sand that is common at or near the bottom of the Fernando the bulk of the formation is composed of rather loosely consolidated fine white and yellow sand and coarser gray sand that grades here and there into thick beds of loose conglomerate. The conglomerate is made of well-worn pebbles, mostly of flint and hard shale, embedded in a coarse sandy matrix. Locally the sand and conglomerate are extremely hard, owing usually to the presence of a large number of mollusk shells from which a calcareous cement has been derived. The most prominent bed of conglomerate, and one that seems to be constant over the whole region, occurs from 800 to 1,000 feet up in the series (above the lowest horizon) just north of Canada de los Alisos, on La Laguna grant. What is probably the same bed is well exposed in cliffs west of Canada Laguna Seca, $1\frac{1}{2}$ miles south of the Los Alamos Valley. This loose aggregate of sand and pebbles in alternating strata of coarse and fine material is dominantly composed of the light-colored pebbles of Monterey shale. Pebbles of other varieties occur more sparingly. Above the conglomerate lies a stratum of limestone that is constant over the whole region and seems to mark a division in the Fernando. There are two or more massive beds of hard limestone interbedded with soft, gray, very alkaline, earthy material, making a total thickness ranging from 10 to perhaps 50 feet. Its fossils indicate that it is of fresh-water origin, and possibly it marks the base of a fresh or brackish water series. The portion of the Fernando overlying this limestone probably corresponds to the fresh-water Paso Robles formation of the Salinas Valley described by Fairbanks in the San Luis folio. In some places where this higher portion of the Fernando above the limestone has not been worn away, it is found to consist of little-consolidated beds of fine sand, gravel, and clay that look as if they might have been laid down in fresh water, but no proof of their origin has been found. Such beds are well exposed in the foothills of the San Rafael Range north of Santa Ynez, where they weather characteristically into cliffs at the summit of hills. A view of such an exposure is given in Pl. VI, A (p. 46), which affords a good idea of the rough alternating beds of coarse material. No good lithologic or paleontologic criteria are known by which this series may be separated from the lower portion of the Fernando, and they are therefore mapped *as a unit*.

STRUCTURE.

As has been stated, the Fernando is generally so nearly conformable with the Monterey that it is difficult to draw a line between them on the basis of a discrepancy in dip. Nevertheless, it is in general true that folding has been gentler in the Fernando than in the Monterey. It would seem that the older formation had been disturbed in varying amounts, in some places severely and in others gently, during the process of uplift that put an end to its period of deposition. As a result the dips at the present time in the Fernando are apt to be less steep than in the Monterey, but folding has gone on largely along old lines, so that conformity in strike between the two formations is the rule.

Wide, low folds are characteristic of the structure in the Fernando within the Santa Maria basin region. This is illustrated by the broad anticlines in this formation in the Solomon Hills, the broad anticline in the Purisima Hills, and the synclines in the Los Alamos and Santa Rita valleys, in which the dips range from 5° to 25° as a rule for a long way on either side of the fold and rarely become steeper than 30° or 35° . In places, as south and west of Sisquoc and west of Canada Laguna Seca, the beds are almost if not quite horizontal, but this is exceptional. Curves and plunges in the pre-existing low folds in the Monterey gave rise to structural basins in which the Fernando was deposited as a filling. Such was the origin of the oval area of Fernando sand covering the eastern portion of the Todos Santos y San Antonio grant. This basin is the westward extension of a great synclinal basin that runs from that locality first eastward and then southeastward across the Los Alamos, La Laguna, and Corral de Quati grants and has determined the position of the



crossing Labrea Creek. In the first two the dip of the beds is moderate and the disturbance is not great.

DISTRIBUTION.

An idea of the distribution of the Fernando may be well obtained from the map (Pl. I, in pocket), as it is not covered by so many formations as the older series. It is much more widespread near the surface, however, than appears on the map, since it is probably present and hidden by only thin deposits over a great part of the area mapped as terrace deposits and alluvium.

The general character of the Fernando is that of a filling. Its soft, loose, spreading sands, which preserve poorly evidence of low folds, form moundlike hills and broad valleys that convey the idea of a filled topography. But, on the other hand, harder beds and surface cappings due to hardening by iron oxide, which not uncommonly produce sharp, square outlines, are marked features of the topography, as in the vicinity of Mount Solomon, at the head of Howard Canyon. On the northeastern border of the Casmalia Hills, between Schumann and Graciosa Canyon, a lime-hardened sandstone predominates and forms a prominent ridge. In the Santa Rita Hills the lines of structure that there curve around from a westerly direction to the southeast are brought out by the resistant limestone which supports the northeast flanks of the hills. The wide-stretching foothills of the San Rafael Range north of Santa Ynez have a character all their own. They are formed of gravel, clay, and sand that have the appearance of belonging to a fresh or brackish water series, and they stand out with many bold faces that have been cut in the soft formation, as illustrated in Pl. VI, A. Elsewhere the dominant character of the Fernando and its topographic forms are due to the soft sand which forms the major portion of the series.

EVIDENCE OF AGE.

At least five and probably six distinct horizons are recognizable in the Fernando by means of characteristic fossil faunas. The localities at which these different faunas occur, named in their probable relative order, beginning with the oldest, are as follows:

- (a) South of Waldorf in soft shale; south and east of Sisquoc in fine sandstone.
- (b) "Sea-urchin bed," Squires (Santa Maria Oil and Gas) lease; California Coast lease; south of Graciosa-Western Union wells; west of Harris Canyon; vicinity of Hill wells in the Lompoc field; and near head of Howard Canyon.
- (c) Waldorf asphalt mine, railroad cut 1 mile northeast of Schumann; Pennsylvania asphalt mine at east end of Graciosa Ridge; all in gray shale or fine gray sandstone.
- (d) Waldorf asphalt mine; railroad cut 1 mile northeast of Schumann; Fugler Point asphalt mine; Sisquoc (or Alcatraz) asphalt mine; and points along north flank of Casmalia Hills, in coarse sandstone or conglomerate.
- (e) East end of Folsom lease in soft sandstone.
- (f) Fresh or brackish water beds immediately west of the mouth of Canada Laguna Seca.

The beds at horizon *a* are of marine origin, are probably upper Miocene in age, and correspond in a general way to Fairbanks's Santa Margarita and Pismo formations. Those at horizons *b*, *c*, *d*, and *e* are of marine origin, are closely related, belong at the base of the Pliocene, and are in a general way the equivalents of the middle Purisima and lower and upper San Diego formations. At horizon *f* are beds of fresh-water origin, probably representing Fairbanks's Paso Robles formation and Lawson's marine Merced formation.

The following is a list of the fossils obtained from the Fernando:

Fernando (upper Miocene-Pliocene-Pleistocene) fossils from the Santa Maria district, California.

[illegible]

Fernando (upper Miocene-Pliocene-Pleistocene) fossils from the Santa Maria district, California—Continued.

	4469	4471	4472	4473	4474	4475	4476	4477	4481	4485	4486	4487	4488	4489	4490	4491	4492	4506	4523
<i>Lymnaea alamosensis</i> Arnold (Pl. XXI, figs. 6, 7) a																			
<i>Macoma nasuta</i> Conrad (Pl. XXII, fig. 5)		x		x	x		x			x									x
<i>Macoma</i> sp.				x															
<i>Macoma</i> cf. <i>secta</i> Conrad					x														
<i>Macra</i> sp.							x	x		x									
<i>Miopeleona oregonensis</i> Dall				x															
<i>Modiolus rectus</i> Conrad				x	x	x				x									
<i>Monia macrochisma</i> Deshayes					x														
<i>Muricea</i> sp.					x														
<i>Nya truncata</i> Linné					x														
<i>Nytilus</i> sp. indet.					x														
<i>Nassa californiana</i> Conrad (Pl. XXIV, fig. 4)		x				x	x	x	x	x						x			
<i>Nassa waldorfensis</i> Arnold (Pl. XXI, fig. 17)				x	x														
<i>Natica clausa</i> Broderip and Sowerby (Pl. XXI, fig. 16)				x	x	x													
<i>Neverita reclusiana</i> Petit (Pl. XXI, figs. 14a, 14b, 15)					x	x	x												
<i>Ocenebra lurida</i> Middendorf					x														
<i>Ocenebra micheli</i> Ford var. <i>waldorfensis</i> Arnold (Pl. XXI, fig. 10)				x															
<i>Olivella biplicata</i> Sowerby					x		x												
<i>Olivella</i> cf. <i>intorta</i> Carpenter									x										
<i>Opalia anomala</i> Stearns				x	x														
<i>Opalia varicostata</i> Stearns				x	x														
<i>Ostrea veatchii</i> Gabb (Pl. XXIII, fig. 10)				x	x														
<i>Ostrea</i> possibly <i>veatchii</i> Gabb					x														
<i>Panomya</i> cf. <i>ampla</i> Dall						x													
<i>Panopea generosa</i> Gould		x		x	x	x						x							
<i>Pecten</i> (<i>Plagioctenium</i>) near <i>cerrosensis</i> Gabb						x													
<i>Pecten</i> (<i>Patinopecten</i>) <i>healeyi</i> Arnold (Pl. XXVI, figs. 1, 2)					x														
<i>Pecten</i> (<i>Pecten</i>) <i>hemphilli</i> Dall (Pl. XXV, fig. 5)					x														
<i>Pecten</i> (<i>Chlamys</i>) <i>lawsoni</i> Arnold (Pl. XXV, fig. 3)			x	x		x													
<i>Pecten</i> (<i>Patinopecten</i>) <i>oweni</i> Arnold (Pl. XXV, figs. 2a, 2b)										x									
<i>Pecten</i> (<i>Pecten</i>) <i>stearnsii</i> Dall (Pl. XXV, figs. 1a, 1b)							x												
<i>Pecten</i> (<i>Chlamys</i>) <i>wattsi</i> Arnold (Pl. XXV, fig. 4)							x												
<i>Phacoides annulatus</i> Reeve (Pl. XXIII, fig. 8)		x	x	x	x														
<i>Phacoides intensus</i> Dall (Pl. XXIII, figs. 9a, 9b)					x														
<i>Phacoides nuttallii</i> Conrad var. <i>antecedens</i> Arnold (Pl. XXII, fig. 6)		x						x											
<i>Pholadidea ovoidea</i> Conrad (Pl. XXII, figs. 1a, 1b)				x	x		x	x											
<i>Pholadidea</i> (?) sp. indet.																			x
<i>Platydont cancellatus</i> Conrad var.					x														
<i>Pleurotoma</i> (<i>Borsonia</i>) sp. a					x														
<i>Pleurotoma</i> sp. b						x													
<i>Priene oregonensis</i> Redfield var. <i>angelensis</i> Arnold (?)						x													
<i>Priene oregonensis</i> Redfield (Young) (Pl. XXI, fig. 2)					x														
<i>Purpura crispata</i> Chemnitz (Pl. XXII, fig. 2)						x													
<i>Saxidomus gracilis</i> Gould					x														
<i>Saxidomus</i> (?) sp. a						x													
<i>Scala</i> sp. a					x														
<i>Sigaretus debilis</i> Gould				x															
<i>Siliqua</i> cf. <i>edentula</i> Gabb				x															
<i>Soen</i> cf. <i>sicarius</i> Gould					x	x	x	x											
<i>Spisula catilliformis</i> Conrad var. <i>alcatazensis</i> Arnold (Pl. XXIII, fig. 6)				x															
<i>Spisula sisquocensis</i> Arnold (Pl. XXIII, fig. 1)				x															

a Fresh-water beds in the Fernando formation, 1 mile southeast of bench mark 425, Los Alamos Valley.

Fernando (upper Miocene-Pliocene-Pleistocene) fossils from the Santa Maria district, California—Continued.

	4469	4471	4472	4473	4474	4475	4476	4477	4481	4485	4486	4487	4488	4489	4490	4491	4492	4506	4523
<i>Tapes cf. lacinata</i> Carpenter.....		X			X		X												X
<i>Tapes staley</i> Gabb.....		X			X		X			X									
<i>Tapes tenerrima</i> Carpenter (Pl. XXII, fig. 10).....		X			X		X	X											
<i>Tellina</i> sp.....		X		X		X													
<i>Tellina</i> aff. <i>bodegensis</i> Hinds.....													X						
<i>Terebratalia occidentalis</i> Dall (Pl. XXII, figs. 4a, 4b).....						X													
<i>Thalotia caffa</i> Gabb (Pl. XXI, figs. 4, 5).....						X													
<i>Thracia cf. trapezoides</i> Conrad.....						X													
<i>Thyasira</i> aff. <i>gouldii</i> Philippi.....				X															
<i>Tresus nuttallii</i> Conrad.....				X															
<i>Tritonium</i> sp. indet.....				X												X			
<i>Trochita radians</i> Lamarck (Pl. XXI, fig. 1).....						X													
<i>Trochita</i> sp. indet.....						X												X	
<i>Turritella cooperi</i> Carpenter (Pl. XXI, fig. 11).....			X	X	X														
<i>Venericardia californica</i> Dall (Pl. XXIII, fig. 4).....			X	X	X	X													

4469. One hundred yards northeast of California Coast oil well No. 3, 1 mile east of Divide, and 3 miles southeast of Orcutt.

4471. Alcatraz asphalt mine, 3 miles east of Sisquoc.

4472. Pennsylvania asphalt mine, 3½ miles southeast of Orcutt.

4473. Waldorf asphalt mine, 3 miles south-southeast of Guadalupe.

4474. Railroad cut 1 mile north of Schumann station.

4475. Fugler Point asphalt mine, 1 mile north-northeast of Gary, at head of Santa Maria Valley.

4476. Asphaltum layer above Monterey shale, near Folsom well No. 3, Santa Maria oil field, 3 miles southeast of Orcutt.

4477. Near Folsom well No. 4, Santa Maria oil field, 2½ miles southeast of Orcutt.

4481. Five miles N. 30° E. of Lompoc bench mark 95, in prominent sandstone beds around Purisma oil wells.

4485. One-half mile south of Sisquoc.

4486. *Echinarachnius ashleyi* horizon, immediately west of Santa Maria Oil and Gas Company's well No. 4, 2 miles southeast of Orcutt.

4487. Immediately east of head of Howard Canyon, 4 miles north-northeast of Los Alamos. *Echinarachnius ashleyi* horizon.

4488. On ridge south of road about 2½ miles northwest of Blake.

4489. Southeast side of La Zaca Creek, where it empties from steep canyon; at base of asphalt sandstone in shale, 8 miles north of Los Olivos.

4490. Four miles east-northeast of Los Alamos, on Cuaslui Creek.

4491. Gully 2½ miles west-northwest of Blake.

4492. One and three-fourths miles S. 5° W. of bench mark 425 of Los Alamos Valley, one-half mile northwest of sink on top of ridge.

4506. One mile southeast of summit of Redrock Mountain, along ridge, near 1,500 foot peak.

inclined slightly toward the ocean or the line of drainage, and ranging in size from tens of square miles to only a few feet square. The more extended terraces fringe the coast line and the larger valleys and cover areas of low hills. The smaller ones are scattered over ridges and hilltops and along the smaller valleys. These terraces are covered with a thin coating of sand and gravel, and here and there with clayey material. The distribution of the deposits is well shown on the map, with two general exceptions. In the first place, many of the strips of land along valleys mapped as covered with terrace deposits may not represent true terraces, as it is almost impossible to draw definite distinctions between such horizontally bedded valley fillings, true terrace cappings, and recent alluvium. All post-Fernando deposits in small valleys are therefore mapped with the terrace formation, and alluvium is shown only in the extended valley bottoms, where dividing lines between it and the terrace deposits are drawn arbitrarily. In the second place, owing to the lithologic similarity of the Fernando and the terrace-deposit sand and the similar surface appearance of these two formations, the attempt has been made to represent on the map only a few areas of the terrace sand overlying the Fernando. The Fernando is doubtless capped by terrace deposits in many places, but it is usually impossible to tell whether this is true or not. The lines of contact between these formations are of necessity arbitrarily shown.

This similarity causes much difficulty in places in determining whether the deposits belong to the Fernando or to the later epoch, and whether it is necessary to go through a great thickness of Fernando beds or only a few feet to reach the Monterey below. Where fossils, distinct lines of bedding, or tilted strata are present they are indications that the sand belongs to the Fernando.

The terraces are found commonly at all altitudes up to 1,200 feet, and a few even as high as 1,400 feet. None have been definitely recognized at a higher elevation.

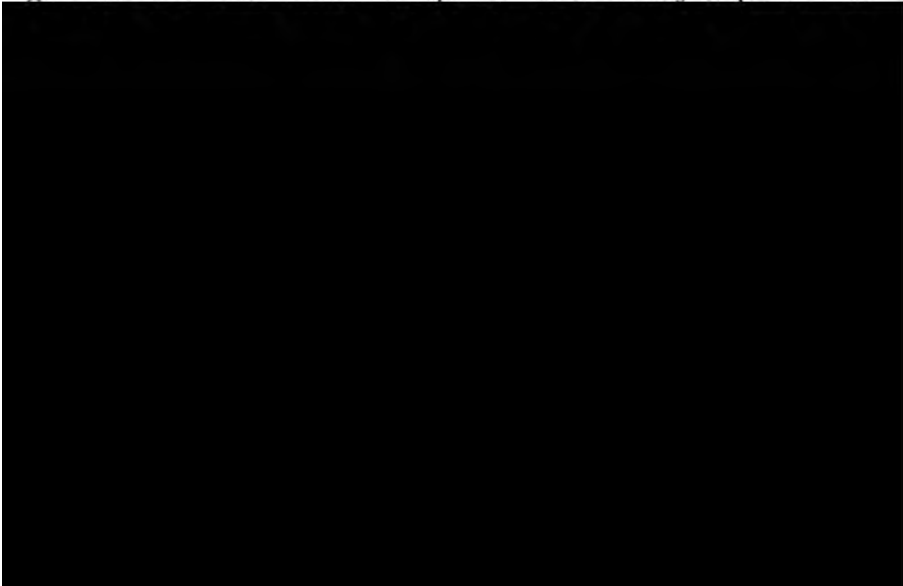
LITHOLOGIC CHARACTER.

The material of the terrace deposits is usually sand and conglomerate, for the most part the former. The sand is medium grained and contains scattering waterworn pebbles. It is normally soft and grayish, but in many places compact, being stained a reddish yellow and hardened by iron oxide or filled with iron-stained concretions. In this superficially compacted state it forms hard cappings on hilltops and slopes. Round, bullet-like, iron-hardened concretions are characteristic of the derived soil. Over much of the surface of Burton Mesa and in other places this deposit occurs as loose, grayish sand, hardened locally by the action of rain water and various salts or oxide of iron. The conglomerate—or gravel, as it might equally well

be called—is composed of boulders, pebbles, and fragments of Monterey flint and shale, besides pebbles of other rocks in smaller quantity. Some of the pebbles are very much waterworn, but in places the number of unworn fragments of shale almost necessitates the use of the word “breccia” in describing the deposits. Evidence of bedding is rarely prominent in the typical terrace deposits, but they invariably appear to lie horizontal, seeming to have been little disturbed by the uplift of the land that brought them to their present elevation.

No fossils have been found in these deposits, but they contain numerous pholas-bored pebbles of Monterey shale, and in places, as on Burton Mesa, the Monterey shale itself, upon which the deposits lie, has been bored by these marine mollusks.

Many of the cappings formed parallel with the surface through hardening by iron oxide have the appearance of being beds with appreciable dip, and are therefore misleading. The thickness of the coating of Burton Mesa is 25 or 30 feet and the cover of the typical terrace in other parts of the region has about the same thickness. Whether it attains a much greater development than this at any place is hard to tell. These shallow coverings hide considerable areas of the Monterey and obscure its structure, but most of the canyons that cut into the terraces reveal the presence of the oil-bearing formation beneath. The thickness of the coatings is not sufficient to make a serious difference in the depth to which it is necessary to drill for oil. The deposits are economically of importance as reservoirs for the oil escaping from the Monterey shale, and thus they give rise to accumulations of asphalt. It is usually impossible to



ORIGIN.

Most of the terrace deposits are probably of marine origin. This is proved in the case of the most typical deposits by the presence of the pholas borings already mentioned. The deposition was carried on in shallow water and much of the material was derived on the spot from the wearing away of the shore line of Monterey shale, the fragments of which were not always subjected to much polishing before being deposited and protected from agencies of erosion. These deposits give undeniable evidence of a great uplift of the coast during Pleistocene time. It seems most probable that the terraced surfaces resulted from marine planation along gradually rising shore lines and that the formation covering them represents the beach and shore deposits. The rise of the land was probably too rapid and the amount of sediment too small to allow much off-shore extension of the deposition. The material that may have been deposited in the deeper places determined by the depressions in the topography has since probably been largely removed by erosion. The terrace deposits themselves have been extensively eroded and in many places are left as mere remnants. Some of them have no doubt been subsequently added to by wind-blown sand.

It is probable that some of the terraces and horizontal Pleistocene deposits along valleys have been formed by streams. Most of the valley fillings were probably laid down in this way. At the mouths of some canyons, as along the western side of Graciosa Canyon, Pleistocene deposits have been built up in the shape of detrital fans, which have since been carved into flat-topped, steep-sided blocks by recent streams.

DUNE SAND.

The prevailing northwesterly wind from the ocean has amassed great deposits of sand in places along the coast. The process has probably been going on all through the Quaternary period and it is hard to distinguish the older of the eolian deposits from those partially or entirely of marine deposition. The line of contact of these formations as mapped is arbitrary.

The greatest mass of dune sand occurs at the northwest end of the Casmalia Hills, where the gradual slope down to the sea from an elevation of about 1,200 feet is covered by loose, yellow sand of probable eolian origin. This drifts about incessantly and is probably still in the process of collecting, being supplied from the long, low, open shore to the north and held in check by the bulwark of the Casmalia Hills on the south. This deposit has a thickness of several hundred feet. At its base along the coast is exposed a basal layer of large boulders and horizontally stratified sand. The original slope of the

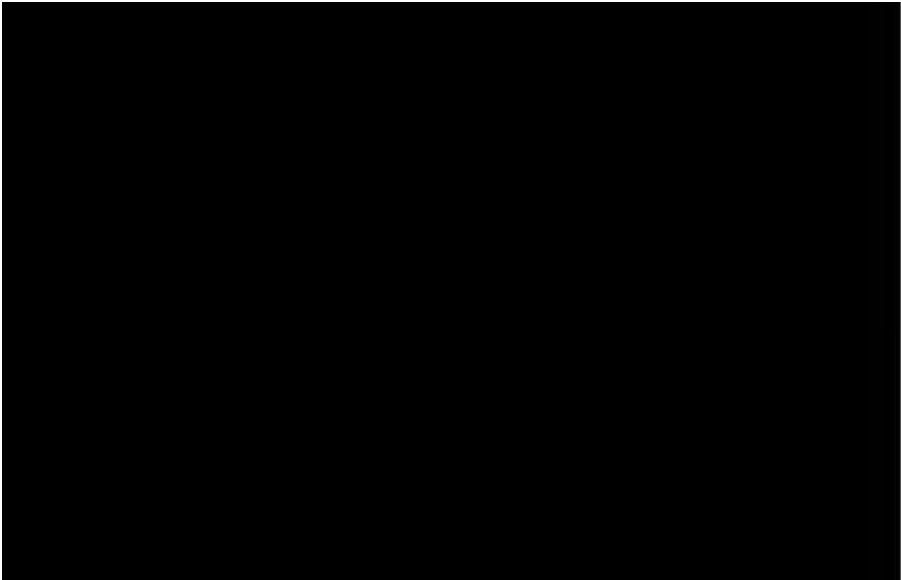
hills was probably at least partly covered during the uplift of the coast by marine terrace deposits similar to those found elsewhere in the region, these being later buried by the gathering wind-blown sand. Recent marine shells are widely scattered over the surface of this sand, but are not considered by the writers as indicating its marine origin. They were probably carried there by Indians or birds.

South of the Casmalia Hills, where the coast is open to the winds, sand dunes are continually forming and covering up the terrace deposits. The sand is not retarded by an inland barrier, however, as on the north of the hills, and no such vast deposit has been formed. The sand is continually being carried into the interior valleys and spread thinly over a wide area.

ALLUVIUM.

All the valleys of this region contain a certain amount of alluvial material and stream gravels, which reach in many localities a thickness of 50 feet or more. In some places the deposit is earthy, in others sandy earth, and in still others pure sand, gravel, or clay. It is as a rule horizontally stratified. Recent deposits of this character attain considerable extent in the wide valleys, but it is not easy to distinguish them from Quaternary deposits of different age or of somewhat different origin. They are mapped as distinct only in the larger valleys and the contact lines are arbitrary. Practically all the hills and valleys within the territory mapped have a covering of soil.

IGNEOUS ROCKS.



and believes to antedate the Knoxville. It is closely associated and intermingled with bodies of diabase and gabbro. This complex forms Point Sal Ridge and the rocky headland of Point Sal. Another complex that he believes belongs in the Knoxville forms a long dike north of Schumann Canyon. It is an exceedingly complicated intrusive mass of gabbro and peridotite that has been penetrated by later dikes of diabase, norite, gabbro, and intermediate types of rock.

The areas mapped as Franciscan (Jurassic) are largely occupied by serpentine that was originally intruded in Franciscan strata. This serpentine may be older than the Knoxville, and the last-mentioned occurrence of gabbro and peridotite may be contemporaneous with it.

Diabase was struck at a depth of 1,300 feet in the Pezzoni well No. 1, southwest of Sisquoc. It is a considerably altered rock composed largely of serpentine and plagioclase feldspar, with some augite, possibly a small amount of unaltered olivine, considerable magnetite, and several accessory minerals. This occurrence is of considerable importance as affecting the prospects for the production of oil in this neighborhood. The question arises whether this diabase has intruded the Monterey, as in the San Rafael Mountains, or whether it is a part of the older igneous formations, in which diabase is common. The fact that the rock is so much altered probably indicates that it belongs to a formerly exposed older formation upon which a fairly high portion of the Monterey shale series has overlapped. It is hardly conceivable that an intrusion at such a depth in the shale could have undergone so much alteration. In either case, whether this diabase marks the base of the Monterey or whether the shales have been intruded by an igneous mass, the conditions are unfavorable for the discovery of oil in the immediate vicinity.

IGNEOUS ROCKS INTRUDING THE MONTEREY.

The youngest igneous rocks occurring in the Santa Maria quadrangle and those of chief interest in the present connection are intrusive in the Monterey (middle Miocene). Such are five small areas of diabase mapped by Fairbanks south of Point Sal and two areas of diabase in the San Rafael Mountains. The age of the two latter is somewhat in doubt, but the metamorphic and disturbed appearance of the Monterey shale in their vicinity indicates that they originated as dikes intruding the Monterey. The shale appears hardened and baked in the immediate neighborhood and narrow tongues of Monterey shale, certainly altered along the contact, extend into the mass on Tepusquet Creek. Along its edges appear patches of *Aucella*-bearing sandstone belonging to the Knoxville, which were probably brought up from below by the intrusion. The diabase in both areas is of dark-green color and coarse texture and exhibits sheared serpentinous facies.

Another intrusion of probable post-Monterey age forms a single outcrop in the hills 7 miles northeast of Point Conception. It is a dike of basic porphyry related to basalt. On one side of the outcrop the bases of horizontally lying rough pentagonal columns are well exposed. It is not known whether the sedimentary rocks through which this is intruded belong to the Monterey or the upper part of the Vaqueros.

GEOLOGIC HISTORY.

EARLIEST PERIODS.

The general geologic aspect of the Santa Maria district is that of a region of comparatively recent geologic formations. Tertiary rocks, in places covered by Pleistocene deposits, are predominant, those of Cretaceous and Jurassic age less widespread, and older formations entirely absent. The Tertiary has received almost all the attention in the present study and little can be said of the history of the region previous to that period. The much-disturbed and metamorphosed Jurassic sediments (Franciscan), intruded by serpentine, form the basement of the whole region, but outcrop only very locally. In Cretaceous time a considerable thickness of marine sediments was laid down, but these deposits were probably not greatly disturbed before the beginning of deposition in the Tertiary. To the present time they have remained unmetamorphosed and no more affected by mountain-making forces than later formations. Igneous intrusions, however, took place at different times in the Cretaceous.

EOCENE PERIOD.

All the greater divisions of the Tertiary, with the possible exception of the Eocene, are represented in the Santa Maria district.



uplift did not occur at the close of Eocene time, but it is probable that orogenic movements did bring to a close the period during which the Eocene sediments were laid down by raising the strata slightly above the sea and preventing for a time further deposition. How long this time was is not known, but it corresponds approximately with the Oligocene.

LOWER MIOCENE PERIOD.

The movements immediately following the deposition of the Eocene caused no appreciable disturbance in the Eocene strata, and when sedimentation recommenced over the same area in lower Miocene time neither the old nor the new strata preserved any positive evidence in their relative position that a time break had occurred. The great masses of coarse conglomerate forming the base of the lower Miocene portion of the group record a change to conditions of very shallow water, and the abrupt change of faunas indicates that a long time interval separated their deposition from that of the subjacent Eocene. It is most probable, however, that the post-Eocene movements, which were gentle, were also somewhat local, and that in portions of the Santa Ynez Mountains to the east of the region under discussion sedimentation was more nearly continuous. At about the close of the Oligocene period the Eocene basin was again depressed; deposition of sediments, almost entirely of detrital origin and very similar to those previously laid down, ensued in a widening area covered by the sea; and subsidence of the land gradually continued. The Vaqueros formation, which resulted from this period of depression, represents the greater part of lower Miocene time.

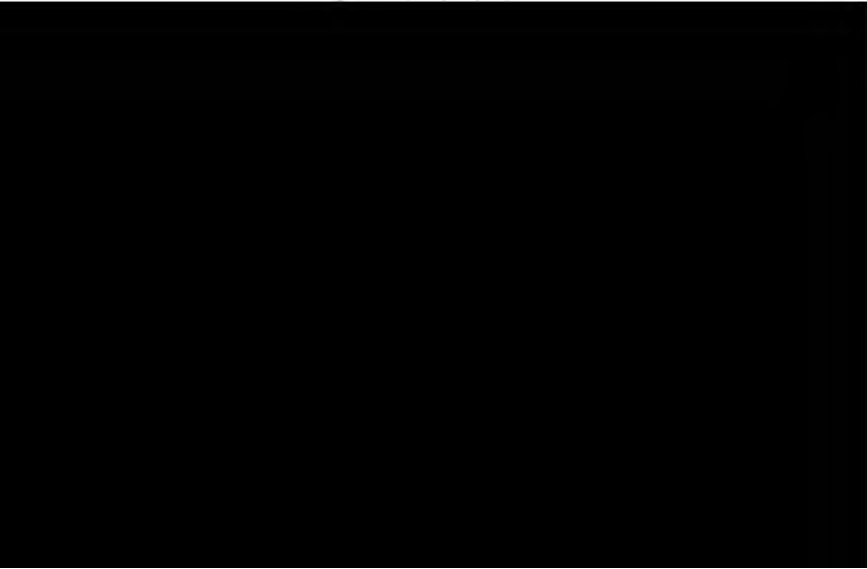
MIDDLE MIOCENE PERIOD.

The middle Miocene (Monterey) shale formation is one of striking individuality, and conditions of unusual character prevailed during its period of deposition. At the beginning of middle Miocene time the land sank over a large part of the region of California now occupied by the Coast Ranges and fairly deep water conditions became prevalent. The wearing away of extended land areas ceased as they became submerged, and the material for the formation of coarse detrital deposits was no longer plentiful. Two varieties of deposits, which were largely of organic origin, were the chief ones to be formed during the long period that followed. These were the laminated limestones and the much more abundant siliceous shales. Silt of extremely fine grain, both of siliceous and argillaceous nature, was swept into the sea waters, probably from considerable distances, and settled down to form a considerable proportion of the deposits; but sand and other coarse detritus found their way only at rare intervals

to the main portions of the quiet sea bottom which was formerly the surface of the land and which had been given a comparatively low relief by the long period of erosion that preceded the submergence.

During the period of transition between the Vaqueros and the Monterey, limestone was formed chiefly, but somewhat inclosed basins where deposits of alkaline mud were laid down apparently existed in places. Such a basin is indicated by the alkaline gypsiferous clays on the south side of the Casmalia Hills, probably representing upper Vaqueros. In some places, as, for instance, in the San Rafael Mountains, sandstone beds were formed early in Monterey time, probably in the neighborhood of locally unsubmerged areas. But later very little sand was deposited anywhere. Further submergence no doubt took place during the period, removing the sources of this sand and allowing to be deposited under fairly constant conditions a thickness of beds greater than a mile. It is not probable, however, that the depth of the sea was at any time as much as this, being more likely closer to half a mile.

During the early part of Monterey time conditions were variable, calcareous and siliceous deposits alternating, probably as a result of alternating temporary predominance in the sea of organisms with calcareous or siliceous shells. As the period progressed the siliceous organisms became more predominant and remained so, making up a large fraction of the total bulk of the Monterey formation. It was an age of diatoms. These small marine plants lived in extreme abundance in the sea and fell in showers with their siliceous tests to add to the accumulating ooze of the ocean bottom, just as they are forming ooze at the present day in some oceanic waters. It is well known that diatoms multiply with extreme rapidity. It has been



period. Acidic volcanic ash of a rhyolitic type was ejected, and it settled in the ocean to form regular beds of considerable thickness and extent interstratified with the other sediments. The occurrence of ash interbedded with diatomaceous earth that probably belongs fairly high in the Monterey formation indicates that these eruptions did not cease in the early part of middle Miocene time. Neither the centers of eruptions nor any lava equivalents of the ash have been found in the field. Similar eruptions were characteristic of the lower and middle Miocene for long distances north and south of this region.

LATE TERTIARY AND EARLY QUATERNARY PERIOD.

The Monterey period of deposition was brought to a close by orogenic movements which folded the shales and lifted them above the sea in many places. In some regions the folding was intense, the greatest disturbances accompanying the uplift of the mountain ranges to an altitude of thousands of feet. The San Rafael Mountains, which were upheaved at this time, probably extended along the lines of former mountains, and some smaller mountainous or hilly areas likewise, such as the Casmalia Hills and perhaps portions of the Santa Ynez Range, followed former zones of uplift. But for the most part the Santa Ynez Range was probably new. It is doubtful whether it was ever completely covered by Monterey sediments, and its structure may have been determined by minor folding previous to the beginning of the Monterey, but it is probable that this range did not have any approach to its present proportions until after middle Miocene time. In other regions low, broad folds were formed during the post-Monterey disturbance and the strata were not upheaved to a great altitude; such was the case in parts of the basin region between the San Rafael and Santa Ynez mountains.

After the formation of the middle Miocene shales they were intruded at several different points by basic igneous masses, mostly of the nature of diabase. The disturbance which put an end to the period was profound and this igneous activity was probably an accompaniment of it. The rocks were locally hardened by contact action in consequence of the intrusions.

After an erosion interval, probably of comparatively short duration, the land again sank, though not so extensively nor to such depth as in the previous subsidence, and a large part of the Santa Maria district, especially the lower regions, became submerged. The deposition of the Fernando followed, beginning before the close of the Miocene. Owing to differences in altitude and possibly also to local difference in the amount of subsidence, the deposition began in some places before it did in others. Over the areas in which the Monterey has been only slightly folded, the Fernando beds assumed conformable positions with it. In regions where the Monterey beds

had been more highly tilted the later sediments were laid down unconformably. In places the first Fernando beds were of similar lithologic character to the Monterey shale, being deposited probably under similar conditions or else derived from the redeposition of the shale material. This similarity, added to the bedding conformity, caused the formations to appear as completely conformable and continuous. But the presence in places of layers of brecciated Monterey shale at the base of the Fernando, and in places of true angular unconformities, proves that a period of erosion preceded the Fernando deposition.

After the period of deposition of the finer sediments usually found at the base of the Fernando, shallow-water conditions prevailed. The deposits were almost entirely detrital, the product of erosion on land, much of the material coming from areas of Monterey shale. Fresh-water or possibly brackish-water conditions may have prevailed in the latter part of Fernando time. They certainly did for a time and locally, at least, when the brackish-water limestone beds were formed.

MAIN QUATERNARY PERIOD.

Downward and upward movements of the coastal region were probably in progress during the Fernando period, but were intensified early in Pleistocene time, and disturbance of the strata along the lines influenced by the post-Monterey upheaval took place. In this way the mountain ranges were upraised in their present position and the Fernando became warped along the lines of further folding in the Monterey.

After this uplift erosion set in and eventually removed the Fer-



of wind-blown sand were formed also, and their formation is continuing at present. During the late Quaternary the deposits and topographic forms resulting from all these processes have been carved by erosion; wide areas have been denuded of the thin Pleistocene capping; and in many places bits of terrace deposits are left merely as scattering remnants.

STRUCTURE AND CONDITIONS AFFECTING THE PRESENCE OF OIL.

THE ANTICLINAL THEORY.

The anticlinal theory of oil accumulation assumes that the oil, being of lesser gravity, rises above the water present in porous rocks and collects at the highest possible points in upward folds, being there confined by impervious strata arching over the folds. The presence of water, according to this theory, is considered as fundamentally necessary for the carrying out of the process of accumulation in anticlines.

The presence of oil in anticlinal folds was repeatedly observed in the eastern part of North America during the latter half of the nineteenth century. E. B. Andrews noted its occurrence along low anticlines in West Virginia and Ohio as early as 1861, and described this occurrence that same year,^a and again, with more assurance of its wide application, in 1866.^b

In 1863 the Canadian geologists,^c in describing the oil springs immediately north of Lake Erie, noted their close relation to the anticlinal structure, and formulated the theory that the rise of the oil is due to the presence of water in the rocks. Their brief statement is as follows:

Some of these springs appear to be on the line of the great anticlinal which runs through the western peninsula, and subordinate undulations of a similar character will be found connected with others. The oil, being lighter than water and permeating with it the strata, naturally runs to the highest part, which is the crown of the anticlinal, whence it escapes to the surface by some of those breaks which are usually found in such positions.

Also in 1863 Sterry Hunt, to whom the above-cited conclusions in the Canadian report are probably due, described the oil of western Ontario as derived from low anticlines.^d

The following quotation is from an account written in 1885 by I. C. White^e of his search for some method of determining the location of gas accumulations:

In the prosecution of this work I was aided by a suggestion from Mr. William A. Earsenian, of Allegheny, Pa., an oil operator of many years' experience, who had

^a Am. Jour. Sci., 2d ser., vol. 32, July, 1861, pp. 85-93.

^b Am. Jour. Sci., 2d ser., vol. 42, July 1866, pp. 33-37.

^c Geology of Canada, Canadian Geol. Survey, 1863, p. 379.

^d Am. Jour. Sci., 2d ser., vol. 35, March, 1863, pp. 169-170.

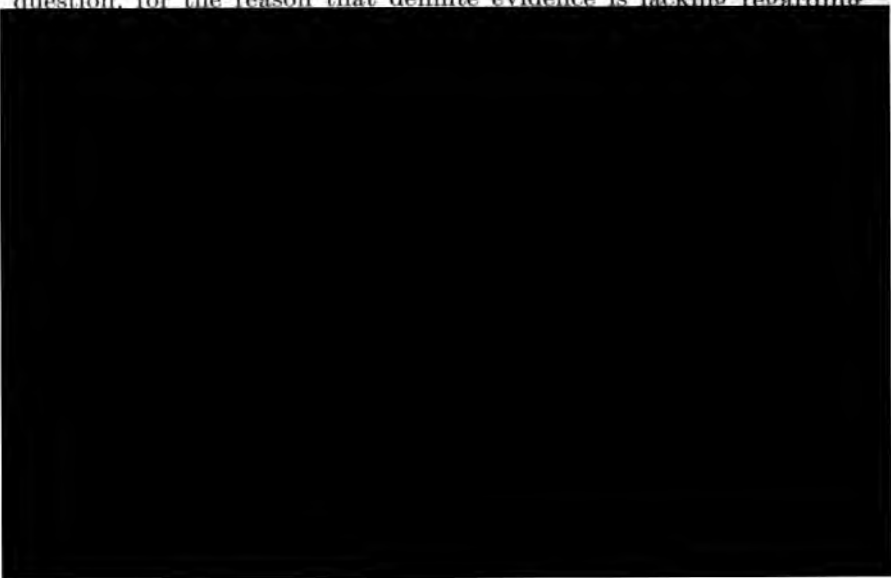
^e Science, vol. 5, No. 125, June 26, 1885.

noticed that the principal gas wells then known in western Pennsylvania were situated close to where anticlinal axes were drawn on the geological maps. From this he inferred there must be some connection between the gas wells and the anticlines. After visiting all the great gas wells that had been struck in western Pennsylvania and West Virginia, and carefully examining the geological surroundings of each, I found that every one of them was situated either directly on or near the crown of an anticlinal axis, while wells that had been bored in the syncline on either side furnished little or no gas, but in many cases large quantities of salt water. Further observation showed that the gas wells were confined to a narrow belt, only one-fourth to 1 mile wide, along the crests of the anticlinal folds. These facts seemed to connect gas territory unmistakably with the disturbance in the rocks caused by their upheaval into arches, but the crucial test was yet to be made in the actual location of good gas territory on this theory. During the last two years I have submitted it to all manner of tests, both in locating and condemning gas territory, and the general result has been to confirm the anticlinal theory beyond a reasonable doubt.

The anticlinal theory was found applicable, according to Redwood,^a by various investigators in the Eastern Hemisphere, in the Caucasian and Carpathian fields, in India, Persia, and Algiers, and as stated by Lyman,^b in some at least of the wells in Japan. Further credence has been lent to it by investigators in various parts of the world in subsequent reports on oil districts. It has, however, not been proved to be of universal application.

ACCUMULATION OF OIL IN THE SANTA MARIA DISTRICT.

In the Santa Maria and Lompoc fields the evidence indicates that anticlinal structure is favorable although probably not absolutely essential to the accumulation of oil. But whether or not this fact is explainable on the basis of the anticlinal theory as previously advanced, and as seemingly applicable to eastern fields, remains a question, for the reason that definite evidence is lacking regarding



near the surface, or at least considerably above the oil-producing zones.

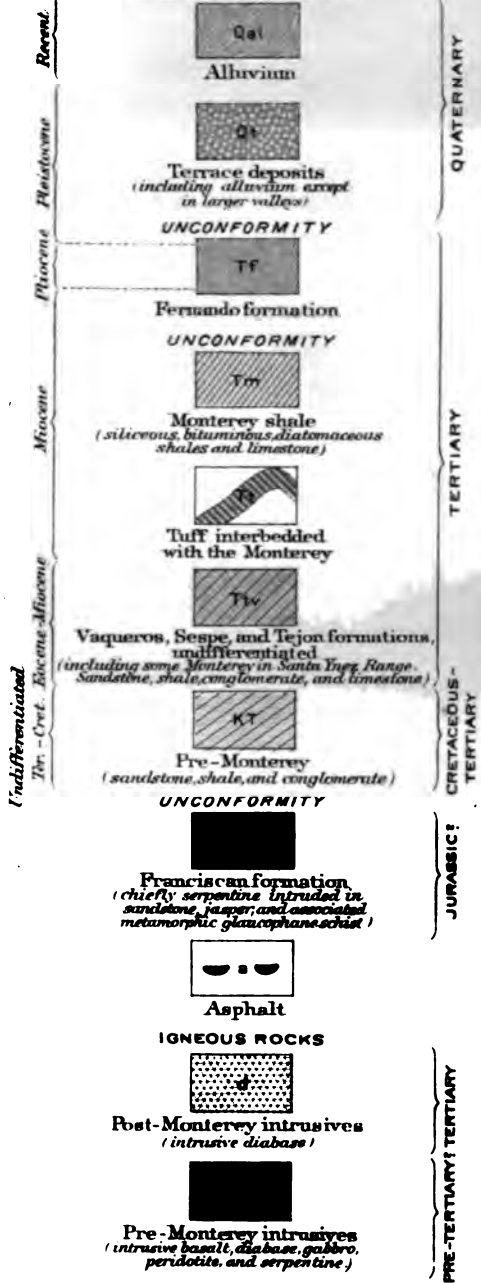
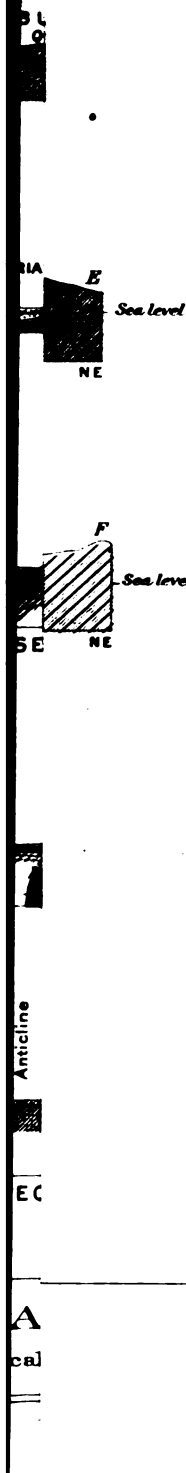
It may be questioned whether the presence of water is essential for the accumulation of petroleum in the upward folds of the strata under the conditions presented by the Santa Maria and Lompoc fields. Here the oil tends to rise to the surface and form seepages wherever channels of escape are offered. This is probably not due to hydrostatic pressure, as there is no evidence that the water tended to rise in the same way; and it is just the opposite of the tendency ascribed to oil by upholders of the anticlinal theory, which would result in the oil descending and gathering in the synclinal troughs on subsidence or removal of the water. In the fields under discussion the oil is always intimately associated with gas. There do not seem to be, as a rule, separated stores of gas and oil, but the two are intermingled, or at least closely brought together, so that one is not usually found without the other, although gas is sometimes found alone. The oil exhibits a tendency to migrate, as shown by its original concentration from widely separated points of origin, by its surface seepage, and by the energetic way in which it rises in the drill holes when a source of it is tapped. This migratory faculty may be ascribed entirely to the presence of the associated gas, which would cause the oil to fill every crevice offering a point of escape or a point of lodgment. If this is granted, it is evident that the points of accumulation of oil will be determined chiefly by the presence of cavities, large or small, offering a place for it to gather. Anticlines, being points of fracturing and in some places opening out of the strata, would afford likely places for the oil to lodge in those beds subject to fracture and for it to be imprisoned by overarching impervious beds.

Aside from ideas as to accumulation of oil after such a fashion, the writers have come to the conclusion that in this region many of the "oil sands," so called, are not true sands, but zones of fractured shale or flint offering interspaces in which the oil can gather. Beds of sand in the Monterey are scarce and thin. Some of the oil-producing zones are very thick, amounting to tens or even hundreds of feet. The oil occurs chiefly in the lower portion of the formation, where brittle, flinty shale is abundant; and as it is a noticeable fact that wherever these hard, flinty layers appear at the surface they are usually much more contorted and fractured than the associated softer shales, which are, in general, only folded and not broken, it seems likely that the same fracturing and resultant formation of an ideal reservoir for the oil takes place in the depths as at the surface. Where it is so fractured, the shale occupies a greater volume than before, showing spaces some of which are open and others partially or wholly filled with chalcedonic or bituminous material. The unfractured beds are more or less impervious to the rapid migration of the petroleum, and so act as barriers to keep the oil in the porous zones.

It is therefore possible that in the Santa Maria district the chief agent in giving the oil mobility, and that of the rocks is the chief factor that controls the matter of its stored most abundantly. Hydrostatic pressure may be an important part. The especially large accumulations may be accounted for primarily by the cavities offered by the upward folds, and secondarily by the presence of beds arching over such folds and affording favorable conditions for the confinement of oil and gas tending to escape. Lesser stores occur at other points within the formation.

INDICATIONS OF OIL.

The chief criteria for judging as to the presence or absence of appreciable quantities in this region have been the attitude of the position in the series, and the surface indications. Other evidences of a local nature have also been taken into account in drawing conclusions from structural indications anticlines have been considered as the chief factors favoring accumulation, inasmuch as oil appears to have gathered in them in a majority of the provenances in this district, other conditions being favorable. The conclusion has been reached that anticlines afford a fairly trustworthy indication to the location of the most important oil deposits. Close folding appears to play a part in this district in depriving the rocks of oil, and excessive disturbance and fracturing is unfavorable for retention. But, on the other hand, moderate folding would appear to be favorable, if not requisite, for the accumulation of stores and probably the most favorable conditions are afforded by ant-





the rose-colored or slaglike rock observed at many places in this and other oil-bearing regions within the Monterey formation. It is fully discussed on pages 48-52. It is the result of the burning of the hydrocarbons that have impregnated the shale, and its presence therefore indicates where seepages have existed.

GENERAL STRUCTURAL CONSIDERATIONS.

The area comprised within the limits of the Lompoc and Guadalupe quadrangles has been subjected to two systems of forces acting obliquely to each other, the one producing structural features which trend northwest and southeast, the other those which trend east and west. (See Pl. VII.) The system causing the northeast-southwest structure was probably the older and dominating one, as it brought forth the highest ranges and most extreme folding and conformed with the great system which has determined not only the Coast Ranges of California but the western border of the North American continent. The forces producing the east-west features, although exceedingly effective from the west end of the Santa Ynez Range eastward to the region south of the end of the San Joaquin Valley, were not so far-reaching as those of the other system and probably began to exert themselves at a later date.

That portion of the area under discussion which lies to the northeast of the Santa Maria Valley is dominated almost completely by structural lines trending northwest and southeast; in the extreme southern portion lines trending east and west prevail. The region between these two areas is occupied by folds and faults, some of whose component parts exhibit allegiance to one system and some to the other, but whose resultant trend is intermediate between the two. In a general way the lines of disturbance as well as the topographic relief within this central province radiate fanlike from the point of divergence of the Santa Ynez and San Rafael ranges east of the town of Santa Ynez.

The forces acting throughout the region have more often found equilibrium in the production of folds than in adjustment by faulting. Several important faults are recognizable, however, and doubtless others will be revealed by detailed work, especially in the San Rafael Range. There is evidence to show that forces have acted intermittently along the same general lines throughout a long period of time.

DETAILED DISCUSSION OF STRUCTURE.

In the field study of the structures of the formations and in the present discussion special attention has been paid to the structure of the Monterey shales, because that formation has apparently given origin to the petroleum and in it the bulk of the oil is stored.

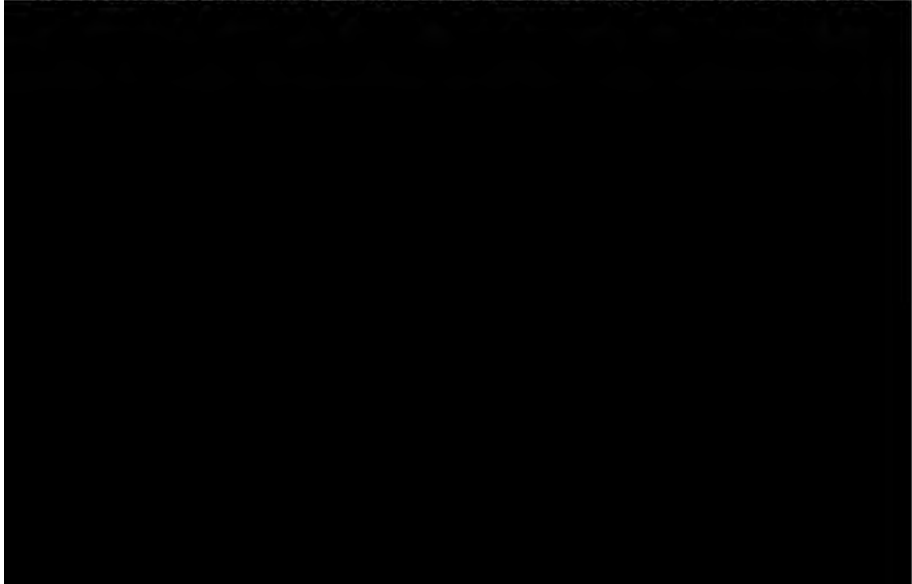
For convenience the two quadrangles will be divided into the three naturally separated portions outlined in a preceding paragraph, viz, the region of the San Rafael Range, which includes all of the territory northeast of the Santa Maria Valley and a line extending southeast of its head; the region of the Santa Ynez Range; and the province of low hills and shallow valleys intervening between the two mountain masses. The reading of the following paragraphs describing the structure of various areas should be accompanied by reference to the map. (Pl. I, in pocket.) For the sake of compactness the conclusions as to the possibilities of productiveness of the Monterey shale have been stated, together with the description of its main structural features.

It must be remembered that in regions of great disturbance such as the shales have undergone in some parts of the area it is difficult to represent by single lines the complexity of the structure. Some of the lines, therefore, mark zones of folding rather than single definitely continuous folds. The dotted lines of structure are purely suppositional.

REGION OF THE SAN RAFAEL MOUNTAINS.

AREAS OF ROCKS OLDER THAN THE MONTEREY.

Whatever succession of beds or structural conditions may once have existed in the Franciscan formation (Jurassic?) in this district, they have been largely obliterated by the successive folding and crushing to which these rocks have been subjected in the long period of time since their first uplift. The shales and sandstones mapped as pre-Monterey, especially where the beds alternate, have preserved the



rather uniformly along the northeastern border of the area, and develop toward the southeast into the syncline crossing Tunnel Canyon and Horse Gulch just north of Sisquoc River. The high, broad ridge between Bone Mountain and Manzanita Mountain is composed of Monterey shale, which lies approximately flat, and toward the northwest becomes one arm of the great syncline which extends through Goodchild's ranch on Labrea Creek and is traceable almost to Colson Fork of Tepusquet Creek. A similar syncline, possibly the same, extends from Colson Fork northwestward across Tepusquet Creek to the margin of the Lompoc quadrangle. The northeastern arm of this fold forms the high ridge extending along the southwestern side of Buckhorn Canyon.

It is possible that the pre-Monterey rocks north of Bee Rock Canyon plunge down monoclinaly under the Vaqueros in a fold at right angles to the wide anticlinal fold that exposes the former. Such a plunge would be apt to give rise to the northeast-southwest table between Bone Mountain and Manzanita Mountain that interrupts the structure to the northwest and southeast, and this table may, therefore, represent a buckling across an otherwise continuous structure.

Southwest of Los Coches Mountain one or more folds are overturned, but the northwestern extensions of these folds have not been examined.

The region southeast of Round Corral and Asphaltum creeks is occupied by several sharp folds which strike in a general northwest-southeast direction. Overturning is not uncommon in this series of folds, one notable example being an anticline on the southern flank of Zaca Peak. West of Round Corral Creek the structure lines bow around from a northwesterly to a westerly or west-southwesterly direction, the folds at the same time becoming less compressed and the conditions for the retention of the oil in the basal sands of the hard shale series correspondingly better.

FAULTS.

There is strong evidence of a fault zone passing north of the narrow area of intrusive rock north of Zaca Lake, and thence northwestward as far as the head of Rattlesnake Canyon. The resultant downthrow along this zone of displacement is on the southwest, probably amounting to a good many hundred feet toward the east edge of the Lompoc quadrangle. Toward the northwest this fault apparently dies out or merges into a syncline.

Just east of Los Coches Mountain there may be another fault which brings up the uppermost Vaqueros on the north. A third fault between the Pliocene and Monterey may extend from a point near the mouth of Round Corral Canyon to Labrea Creek.

Faults also occur along the Franciscan-Fernando contact in the region northwest and southeast of Figueroa Creek, but the resultant throw was not determined. A depositional contact is clearly exposed along this same line just northwest of Alamo Pintado Creek.

EVIDENCES OF PETROLEUM.

Despite the great development of folds within the Monterey area, only here and there do seepages of asphaltic material occur. It would seem that the fractures produced by sharp folding would give adequate channels for the escape of petroleum, and it is surprising to find so few seepages. The best developed of these is on Labrea Creek at and near its junction with Rattlesnake Canyon, and is typical of the localities noted north of Sisquoc River. The oil seepage is associated with small springs of strongly saline and sulphurous water, and the oil has exuded along the bedding planes of the Monterey shales, here thrown into a pronounced anticline which has been flexed in such a manner as to open out the laminae of the shale and thus give better opportunity for the passage of oil. Two wells have been sunk here, but they are shallow and offer no additional data.

The following is a brief statement of the asphalt seepages and breccia deposits occurring in the San Rafael Mountains:

1. Branch of upper Tepusquet Creek. Slight seepage in bed of creek three-fourths of a mile above junction with main stream. At anticlinal axis. Has been located.
2. On Colson Fork of Tepusquet Creek. Black bituminous streaks, veinlets, and pockets, associated with calcareous shales which are considerably folded on a minor scale. This also has been located.
3. Labrea Creek, at and near junction with Rattlesnake Canyon.
4. Sisquoc dairy. Seepage and asphaltic sands along sharply defined anticline which is obscured by later material. Well sunk here, but no record available.



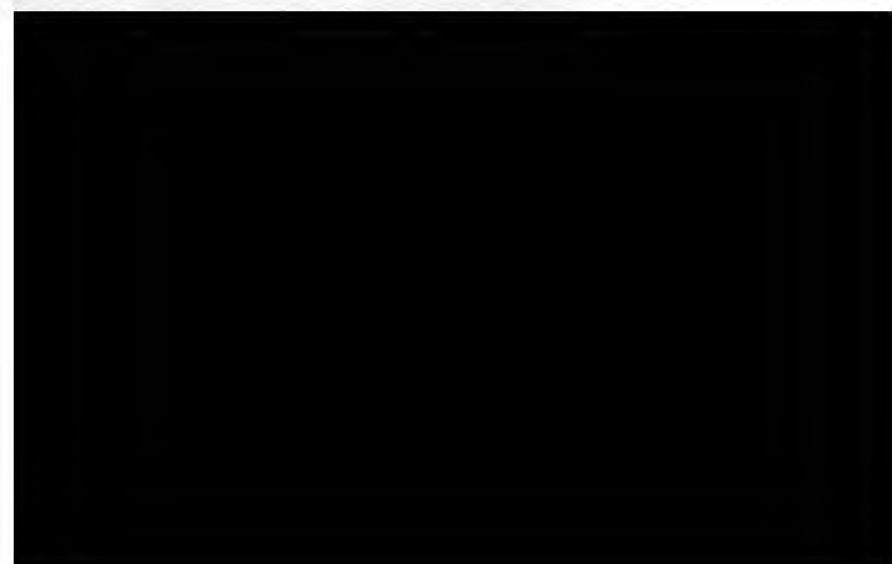
A. ALCATRAZ ASPHALT MINE, 3 MILES EAST OF SISQUOC.

Showing the horizontal Fernando breccia deposits overlying the steeply tilted Monterey shale.



B. UNCONFORMITY BETWEEN TILTED MONTEREY SHALE AND HORIZONTAL PLEISTOCENE SAND AND GRAVEL.

In railroad cut northeast of Casimolia. Photograph by Ralph Arnold.



CONCLUSIONS REGARDING FUTURE DEVELOPMENT.

On account of the greater intensity of the folding and the lack of the thick, more or less unaltered diatomaceous deposits which are found associated with all the proved productive fields in this district, the indications are not so encouraging for good wells in the territory northeast of the head of the Santa Maria Valley as they are in certain other portions of the Lompoc and Guadalupe quadrangles. The areas in the region of the San Rafael Mountains which offer the most inducements for testing by the drill are as follows:

1. North and northwest of Sisquoc post-office, along the anticlines shown on the map (Pl. I, in pocket). There are one or two local anticlines not shown, which might also be prospected with good results. The hard shales exposed in this region are probably lower Monterey and, if such, do not offer as much promise of great accumulations of oil at their base as if they were overlain by the upper part of the formation. The strata in the region above the headwaters of Round Corral Canyon and Asphaltum Creek are too sharply folded to give much hope of the retention of large deposits of petroleum. The asphaltum deposits here and to the southeast indicate that the Miocene was at one time highly petroliferous, but that at least a considerable portion of the oil has escaped.

2. In the Monterey area bordering the head of the Santa Maria Valley on the northeast, both west and east of Tepusquet Creek, wherever the anticlines are not so sharply folded as to give indications of probable loss of their petroleum content by excessive fracturing. The surface evidence of petroleum in this general Monterey area is greatest in the southeastern or more sharply folded portion, but for obvious reasons it seems likely that the chances for the accumulation of economically important deposits of petroleum are greatest in the less compressed area northwest of Labrea Creek.

3. The region about Fugler Point and thence southward and southeastward toward Sisquoc. This territory is doubtless underlain by the oil-bearing beds, but at what depth it is not possible to calculate owing to the fact that the Monterey and Fernando are covered by later sediments. The occurrence of asphaltum at Fugler Point is analogous to that at the east end of Graciosa Ridge, near which very productive territory has been developed. The local dip at the point (25° SW.) would indicate that the best places to drill would be east of the asphaltum deposit; but the uncertainty whether this dip is anything more than a local tilting of the Fernando is so great that conclusions regarding the best localities for exploitation in this immediate vicinity are extremely hazardous. Southwest of Fugler Point, however, there is evidence of the presence of a low

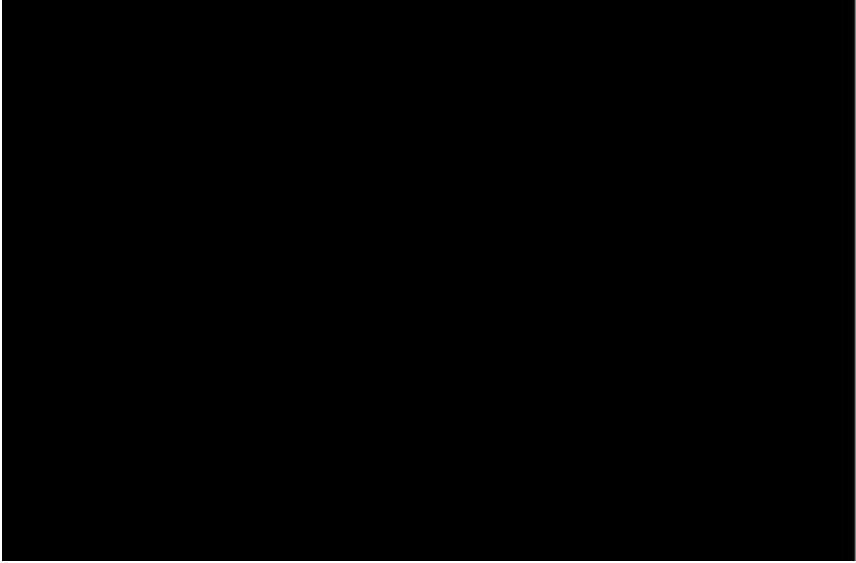
anticline which should yield good returns if penetrated deep enough. This anticline is mentioned further in connection with the Canada del Gato^a area (pp. 88-89).

REGION OF SANTA YNEZ MOUNTAINS.

AREA SOUTH OF LOMPOC.

South of the Lompoc Valley, the Monterey dips in general northward away from the higher portion of the hills, but south of the town of Lompoc is an area of much disturbance, and many folds have been developed on the flank of what may be thus broadly considered as a monocline. These folds have been compressed in different directions and there is a puzzling diversity of dip and strike. There are so many local folds that it is difficult to connect the more important axes, but the general lines of disturbance are continuous for the distance mapped. The main folds south of Lompoc are an anticline near the valley and a syncline north of the Monterey-Vaqueros contact, with a minor anticline and syncline between. The attitude of the beds is extremely variable, the dip ranging in general between 15° and 60°. On either side of the main anticline between Salsipuedes and San Miguelito creeks the hard shales dip away at an angle of 20° to 40°. West of San Miguelito Creek the folds swing out toward the valley or die out on the flank of the monocline, which thus becomes unbroken.

The greater part of the strata in the hills south of Lompoc belong low in the Monterey formation, although higher portions remain in the synclinal folds. The disturbance has been considerable, and erosion has removed the highest parts of the formation, so that the



2



A. B. MONOCLINE IN MONT

About $1\frac{1}{4}$ miles northwest of Casalia. 10-



CASMALIA HILLS.

Photograph by Ralph Arnold.



COMPANIES' WELLS.

Photograph by Ralph Arnold



The conditions along this anticline, especially through the eastern half of its length, favor the occurrence of some oil at least, as the axis exposes beds fairly high in the formation and the folding is gentle. No surface indications of petroleum were found, except a patch of burnt shale south of the road about 1 mile southwest of the highest hill (elevation 1,300 feet) and local outcrops of bituminous black flint and brown shale on the west side of the 800-foot hill about half a mile north of the river and $1\frac{1}{2}$ miles west of the east edge of the Santa Rosa grant.

MAIN PORTION OF THE SANTA YNEZ RANGE.

The Santa Ynez Range is composed chiefly of Tejon and Vaqueros rocks and its structure is therefore much less important in connection with the oil deposits than that of the areas underlain by the Monterey shale. It is dominated by a great southward-dipping monocline that forms a high ridge along the coast, north of which the strata are gently folded along curving lines that reflect two different structural trends. The folds that expose the Tejon-Vaqueros and the underlying Franciscan beneath the Monterey toward the west end of the range are in places abrupt and complex. The anticline of the Santa Rita Hills has the appearance of crossing the Santa Ynez Valley and continuing in a large fold to the southeast.

REGION BETWEEN THE SAN RAFAEL AND SANTA YNEZ MOUNTAINS.

CASMALIA HILLS AND SAN ANTONIO TERRACE.

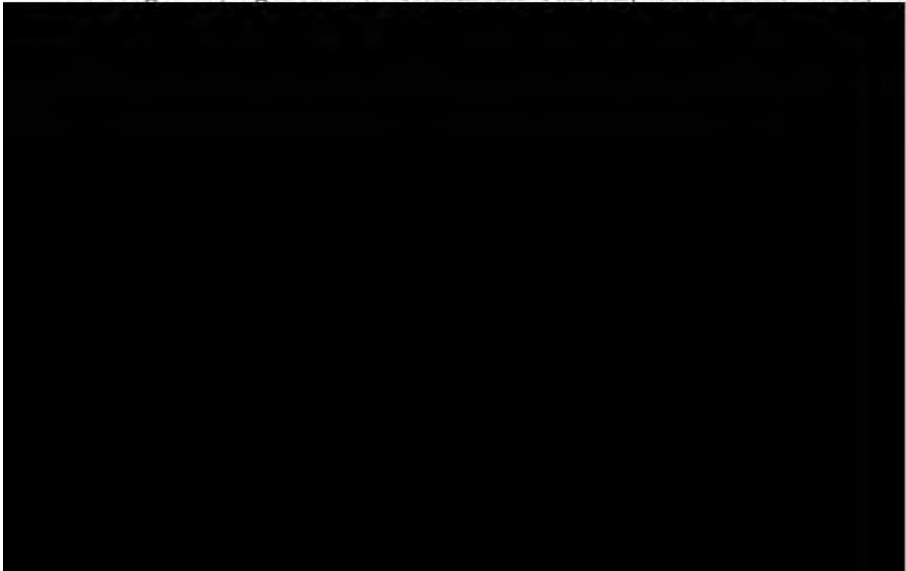
Two dominant structural lines control the region of the Casmalia Hills and the San Antonio terrace. One is a typical fault starting on the coast south of Lions Head and the long area of igneous rocks and running southeastward. About 2 miles west of Casmalia the line is continued by an anticline, which is probably affected by faults at least as far as Schumann Canyon. This anticline plunges more and more toward the southeast and loses its character as a fold, giving place to the eastward-dipping monocline of the San Antonio terrace.

The other structure line is one of varying character, represented on the map as the Schumann anticline. Northeast of the area of igneous rocks that meets the sea at Lions Head Miocene strata form a great monocline, dipping rather steeply to the northeast. In the high region of Mount Lospe and northeast of the long strike ridges (shown in Pl. IX, A, B) that extend southeastward from that peak, this monocline flattens out into a structural platform of very low dip, which on approaching the edge of the steep descent to the Santa Maria Valley bends over and drops off abruptly. The axis along which this steepening of the dip occurs is in a way equivalent

to an anticlinal axis and is the line mapped. In places it is a true anticline, completed by beds of gentle dip that form a broad syncline of the platform on its southwest side. South of Corralillos Creek the structure curves westward and the Schumann anticline is sharply defined and overturned. It is seemingly to be correlated with a large anticline exposed in the Tejon-Vaqueros rocks on the coast north of Point Sal. South of Waldorf this anticline, as shown by the dotted line on the map, is not certainly continuous, but west and south of Schumann the same or a similar fold becomes well developed and the strata dip away from it on both sides. In this portion and southeast of Schumann Canyon its summit is broad, but the dips become very steep farther out on its northeastern flank. It plunges to the southeast and finally dies out.

Asphalt and other surface indications of oil, such as burnt shale and bituminous shale, occur at many places in the Casmalia Hills. The shale is especially bituminous along and near its contact with the Fernando on the northeastern side of that part of the hills which lies north of Schumann, and it has been burnt in a number of places in the same region. Outcrops of burnt shale are prominent on the hill just southeast of Schumann, and near the contact at the northern base of this hill the shale is extremely bituminous. Wells put down in the region about Schumann encounter heavy tar at depths below 2,000 feet, but no paying wells have been struck. It seems likely, however, that at greater depths, possibly 3,000 feet or so, the horizon of the productive flinty beds encountered in the Graciosa Ridge wells will be penetrated and will yield lighter oil in paying quantities.

The region lying north of Schumann Canyon, west of the valley



becomes more nearly normal, both flanks will probably be found productive if penetrated deep enough. The surface structure indicates that the oil horizon plunges to a greater and greater depth under the whole region southeast of Casmalia Creek. The anticline south of Antonio is well defined and conditions favor the presence of oil on both this and the other anticline of the San Antonio terrace.

The main anticline on the coast north of Point Sal, already mentioned, is in the Vaqueros and is doubtless barren of oil. North of this locality the Monterey is decidedly bituminous, but no special circumstances point to the existence of petroleum in large quantity. It is quite possible that the region north of Mussel Rock, the next point to the north, would prove promising if the surface covering allowed the examination of the underlying formations and the determination of anticlines. The structure seems to cause the formations to plunge toward the north from the north end of the Casmalia Hills, and a fairly high portion of the Monterey may underlie the region at the mouth of the Santa Maria Valley.

BURTON MESA.

The plateau known as Burton Mesa is a region of numerous low folds in the Monterey. Along the coast the flinty shales are of low dip, but folded and contorted in a complex way. The folds indicated on the map are the most important ones, but whether or not they are perfectly continuous units across the mesa can not be definitely ascertained on account of the covering of sand over the shale. The mesa appears to be structurally a continuation of the region near Lompoc as much as it is of the Purisima Hills, although topographically it is a continuation of the latter. In the neighborhood of Pine and Santa Lucia canyons there is a thick series of shales striking far to the north of west and directing the structural lines across the Lompoc Valley as if to join those in that region that show a tendency to curve northward. West of Pine Canyon the strike changes. The Pine Canyon anticline shows this curving structure. It is a well-defined fold with broad summits and supports on its flanks a considerable thickness of shale. The dip ranges from 10° to 30° . A characteristic appearance of the shale and dip on the northeastern flank is shown in Pl. IV, *B* (p. 36). North of this fold occur a number of minor flexures and there is some doubt as to the continuity of the anticline mapped at the head of Oak Canyon with the well-defined fold near the coast in the vicinity of Canada Tortuga. A well-marked low anticline occurs near the coast north of Lompoc Landing and probably continues inland. It is probable that either one anticline of considerable importance or several small component flexures start across the mesa between Tangair and San Antonio Creek. The summit of all these anticlines so far

mentioned on Burton Mesa exposes hard shale that is low down in the Monterey, and it is probable that with the removal of all of the higher portion opportunity has been offered for the escape of the greater part of the oil from the basal beds.

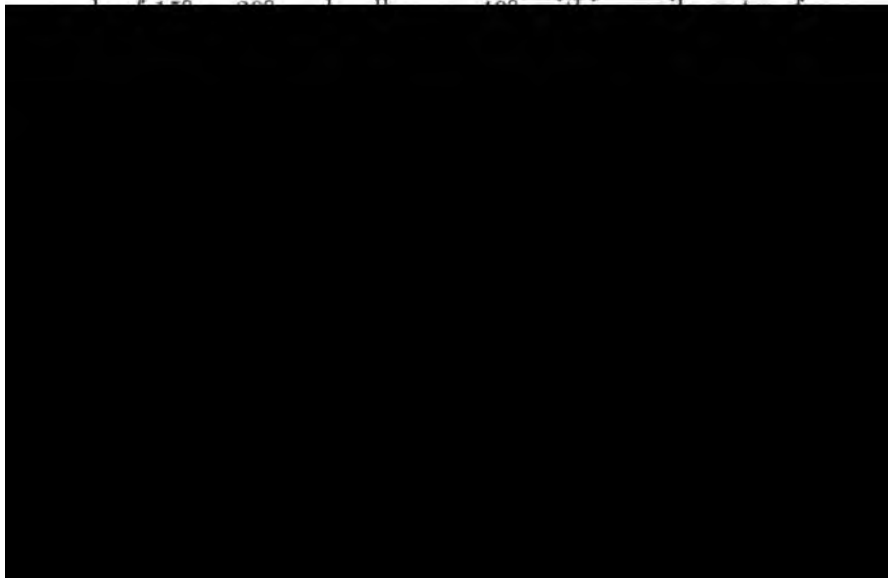
A low anticlinal fold occurs in the northeast corner of Burton Mesa and plunges toward the southeast. As indicated by the dotted line on the map, it is possibly a continuation of the anticline south of Antonio before mentioned and another on the east edge of the mesa that is discussed in connection with the Purisima Hills. The evidence of folds in this northeastern portion of the mesa is scanty, but it is probable that where they occur accumulations of oil are present.

The brittle calcareous and flinty shale of the lower portion of the Monterey that is exposed along the coast edge of Burton Mesa is very bituminous. The petroleum slowly oozes out in some places and collects in tarry patches over the shale. Up Oak Canyon the shale is bituminous, pockets of tar being found in places in the flint on the surface. On the northern border of the mesa, near the point where the road to Lompoc comes up the grade, a 3-inch bed of bituminous sand was found traversing the shale fairly high in the formation.

PURISIMA HILLS.

FOLDS.

The Purisima Hills are formed by one broad anticline which has its axis on the south side of the summit of the dominating ridge. Through the major portion of this anticline's course, from the region north of the Hill wells to a point beyond Redrock Mountain, the beds lie almost horizontal on its summit, becoming gradually steeper up to



• FAULTS AND ASPHALT DEPOSITS.

A thrust fault is well exposed in two forks of Cebada Canyon, where the Monterey has been thrust to the southwest up over the Fernando. The dip of the fault plane is toward the northeast at an angle of about 30°. The movement has amounted to a few hundred feet. The fault zone seems to continue for a considerable distance toward the northwest and to be marked near the Wise & Denigan oil well No. 8 by large asphalt deposits occupying fractures in the Fernando that dip at an angle corresponding to that of the fault plane. The asphalt back of the Wise & Denigan well No. 1 is probably due to oil that has seeped through the same fractured zone and collected in the sandy capping.

The structure of these hills is further complicated by a prominent overturned anticline in the Monterey along the contact with the Fernando southwest of Los Alamos and by what appears to be a fault exposed near the mouth of Canada Laguna Seca. In this fault the Fernando limestone and sand are thrown down several hundred feet on the north, at the edge of the Los Alamos Valley.

In addition to the deposits above noted, asphalt occurs in great abundance south and east of Redrock Mountain, surrounded by a large area of very bituminous shale and burnt shale. Undoubtedly an immense amount of petroleum has escaped here, but it is not probable that the supply is exhausted. On the contrary, the presence of this petroliferous material on the surface, coupled with the favorable structural conditions, points strongly to the existence of rich oil deposits beneath.

A large mass of asphalt is present in the much-fractured Monterey shale west of La Zaca Creek, and very bituminous shale approaching asphalt in character occurs on the creek south of Zaca station. The shale is bituminous throughout the zone of disturbance traversed by this creek south of Zaca. On account of the low position of the strata in the formation and the severe fracturing and folding that have taken place, it seems probable that the conditions have been favorable in this eastern portion of the Purisima Hills for the escape of much of the petroleum.

Small beds of bituminous sands interbedded with soft shale occur in the upper portion of the Monterey just east of Canada de la Puente, about three-fourths of a mile south of the Los Alamos Valley; also on the north side of the Purisima Hills ridge, about 2 miles south of Harris. A small patch of shale that is saturated with bituminous material is exposed in the canyon followed by the road 1 mile south of the Los Alamos Oil and Development Company well No. 1, and the shale is bituminous in the neighborhood of the Todos Santos well.

CONCLUSIONS REGARDING FUTURE DEVELOPMENT.

The Purisima Hills anticlinal fold seems to offer a favorable location for oil wells along most of its south flank. Owing to the plunging of the fold toward its middle, lower and lower strata are reached as its extremities are approached. In the region mapped as Fernando, between the Hill wells and the head of Canada Laguna Seca, the summit beds of the Monterey are overlain by later sand and a well would have to be drilled to a great depth before reaching the oil horizon. East and west of that region the oil horizon probably approaches nearer to the surface. In the vicinity of Redrock Mountain, especially to the west of it, the conditions seem very favorable for the occurrence of oil. Farther east, near La Zaca Creek, a much lower portion of the Monterey is exposed and the rocks have been affected by considerable disturbance, so that it is less likely that large accumulations of oil will be found there.

AREA AROUND SANTA YNEZ.

The Santa Ynez anticline is a distinct steep fold exposed southeast of the town of that name. It supports on its flanks a thickness of at least 2,500 feet of calcareous and porcelaneous shales belonging to the lower portion of the Monterey. The dips at the axis range between 50° and 80° , but become lower toward either side. This fold is seemingly a structural continuation of that of the Purisima Hills, and it probably extends under the gravels of the region around Santa Ynez, its axis passing approximately under that town. But it is doubtful whether it is actually the same as either of the anticlines that are shown on the map as stopping indefinitely near the



SOLOMON HILLS AND AREA NORTH OF LOS OLIVOS.

GENERAL FEATURES.

Three anticlines dominate the structure of the Solomon Hills. These are, in order from west to east, the Mount Solomon anticline (first worked out and named by W. W. Orcutt), the Gato Ridge anticline, and the La Zaca Creek-Lisque Creek anticline. In addition to these there are at least three or four minor anticlines associated with the first named, and at least one north of that on Gato Ridge.

MOUNT SOLOMON AND ASSOCIATED ANTICLINES.

Structure.—The details of the northwest end of the Mount Solomon and associated anticlines are shown on the contour map (Pl. X, p. 92). Whether or not the anticline extending through the Santa Maria Oil and Gas and the Escolle properties should be considered the true extension of the Mount Solomon anticline, or whether the Hartnell anticline should be so considered, is impossible to decide with the data at present available. It is the writers' opinion that the Mount Solomon and Hartnell anticlines are the result of the same set of forces and should therefore be considered as one fold, but that the evidence offered by the data used in compiling the map favored the relations shown on Pl. X. The mapping of the Pinal, Hobbs, and Newlove anticlines is based almost entirely on evidence furnished by the drill, although certain superficial evidence strengthens the theory of their presence.

The southeastern portion of the Mount Solomon anticline gradually fades out into the southern flank of the Gato Ridge anticline, losing its individuality toward the southeast end of the Mount Solomon ridge. The northeastern flank of the anticline is much the steeper, dipping from 20° to 38° in the region of Mount Solomon, and gradually flattening out from that locality southeastward.

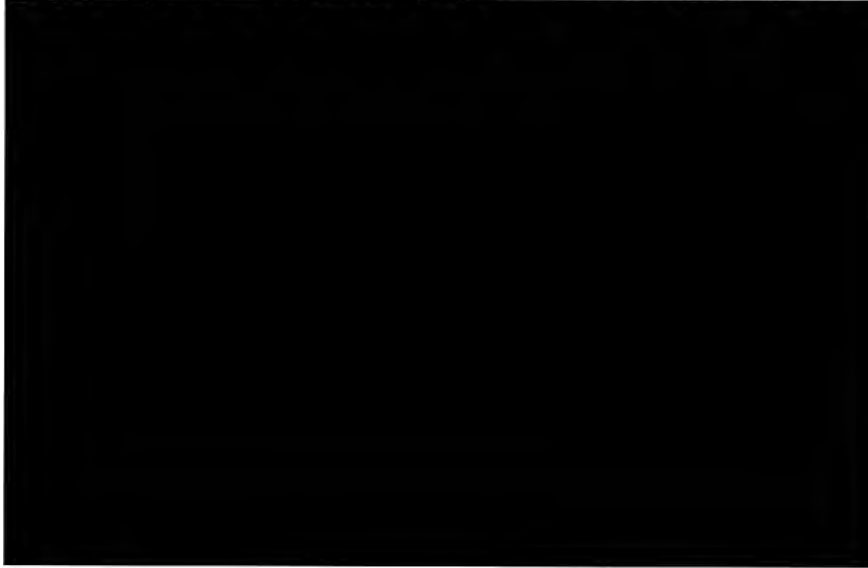
The Western Union anticline is a well-developed flexure with steep northern flank just south of the eastern group of Western Union wells, but its identity becomes more and more obscure as it fades into the southwestern flank of the Gato Ridge anticline in a similar manner to the Mount Solomon anticline, just south of the latter's southeast end.

The relations existing between the Mount Solomon and Schumann anticlines are vague, although it is certain that they are not in alignment and therefore can not possibly be one continuous feature. If the Hartnell and Mount Solomon anticlines are considered as one, the relations which exist between this united anticline and the Schumann anticline are exactly analogous to those which exist between the Mount Solomon and Gato Ridge and the Gato Ridge and La

Zaca Creek-Lisque Creek anticlines, viz, the adjacent anticlines are en échelon with each other, each plunging down past the end of its neighbor. Graciosa and Harris canyons, particularly the former, are the superficial reflection of the syncline between the ends of the Mount Solomon and Schumann anticlines, and Solomon Canyon and Canada de los Alisos occupy analogous positions between the Mount Solomon and Gato Ridge and the Gato Ridge and La Zaca Creek-Lisque Creek anticlines, respectively.

Asphaltum deposits.—Practically the whole top of Graciosa Ridge is capped by post-Monterey sandstones and conglomerates, which are heavily charged with asphaltum. Asphaltum also occurs as veins penetrating the Monterey and post-Monterey beds at the east end of the ridge, and a fine example of asphaltum veins and veinlets filling the joint cracks in the Monterey is to be seen beside the road leading up to the Santa Maria Oil and Gas (Squires) well No. 4. This occurrence of the asphaltum in the joint cracks of the shale gives a clew to the probable channels through which the oil migrated from the depths to the surface, and leads to the general conclusion that joint cracks are the reservoirs and channels of migration of the oil in many of the productive strata of this field.

Conclusions regarding future development.—It is obvious from a glance at the contour map (Pl. X, p. 92) and a perusal of the detailed description of the developed areas that practically all of the territory covered by contour lines is productive. The only part of the region about which the compiler of the map has any misgivings as to productiveness is that occupying a general synclinal position south of the great bend in the Mount Solomon anticline. These misgivings are partially alleviated, however, by the idea that probably the



the crest of the ridge between Canada del Gato and Solomon Canyon and for a considerable distance to the east is coincident with the highest topographic features. In general, the anticline plunges from the southeast toward the northwest, the lowest beds along its axis being exposed in the region of Canada Arena. The Fernando is the only formation exposed along the entire length of the anticline. With the exception of some diatomaceous beds which closely resemble and were at first mistaken for Monterey shale, the rocks exposed are sandstone and conglomerate.

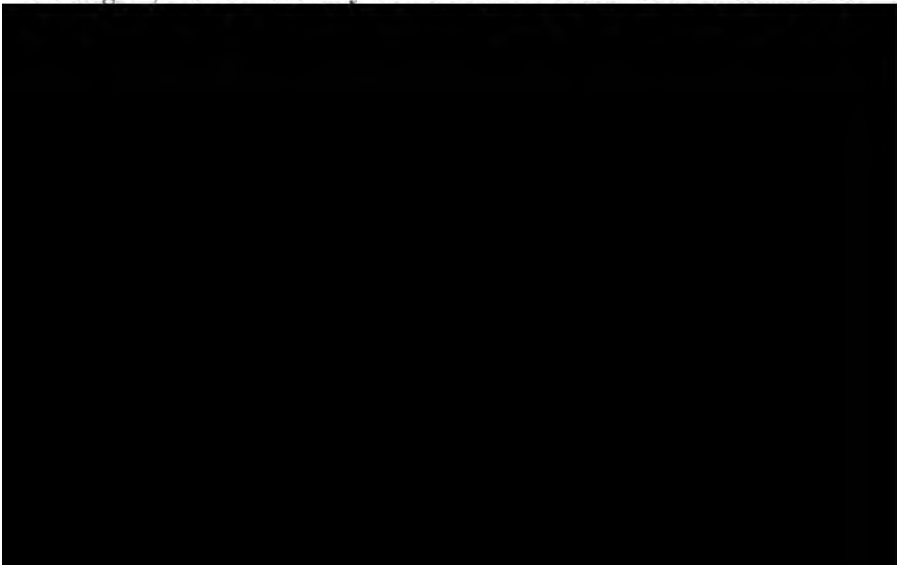
The northwestern portion of the fold, from the Howard Canyon road northwestward, is a gentle arch with dips on the flanks rarely more than 5° , except northwest of Los Alamos, where the dips of some of the youngest beds exposed change abruptly from 3° or 4° to 15° . The northwestern extremity of the anticline fades off into the low slopes toward the Santa Maria Valley. From Howard Canyon eastward the southerly dip increases rapidly in steepness until in the region of Canada de los Coches it attains a slope of 25° to 35° , the steepest dip being at the junction of the canyon last named and Canada Arena. Although the southerly dip increases in steepness toward the east along the anticline, the dip of the northern slope becomes less, ranging from 12° or 15° in the region of Howard Canyon to 3° or 4° just west of Canada Arena, and finally changing to a gentle southward slope in the region of Cuaslui Creek, thus fading into the southern flank of one of the folds emanating from the region at the head of Round Corral Canyon and Asphaltum Creek. In the region of Cuaslui Creek the flexure is therefore not a typical anticline in the regularly accepted sense, the horizontal being used as datum, but in every other way it conforms to the characters of such a structural feature.

On the ridge north of the central portion of Canada del Gato and extending indefinitely northwestward out into the Santa Maria Valley a mile or so southwest of Gary is a low anticline, the southeastern end of which merges into the almost horizontal northern flank of the Gato Ridge anticline. At no place along its course is this structural feature well developed, although it appears to be fairly persistent for a considerable distance.

Evidences of petroleum.—Very little surface evidence of the existence of petroleum in the Gato Ridge anticline is to be had along its course. Near its axis in Cuaslui Creek and north of the head of Howard Canyon, however, the Fernando shale is slightly bituminous. The Pezzoni well, in Canada Arena; the Williams well, near Canada del Gato, $1\frac{1}{2}$ miles west of the Howard Canyon road, and the Palmer Oil Company's well No. 1, 1 mile west of the lower part of Canada del Gato, all approximately a mile north of the anticline, offer indisputable evidence of the presence of the oil-bearing rocks

along a considerable extent of its northern flank. In the region of the Pezzoni well an unproductive oil and gas bed is encountered at about 1,200 feet below the surface, immediately followed by a diabase or lava rock in which the ferromagnesian minerals have been weathered to serpentine. In the Williams well the same or a similar oil and gas bed occurs much lower. The well was abandoned owing to the terrific gas pressure, which heaved heavy tar up into the hole and stopped operations. The Palmer well is productive, yielding oil of 16° or 17° gravity. Although not directly associated with the minor anticline northeast of Canada del Gato, the asphaltum occurring at Fugler Point, 1 mile north of Gary, is important in indicating the probable presence of petroleum in the upper end of the Santa Maria Valley.

Conclusions regarding future development.—The region north of the Gato Ridge anticline, from the vicinity of Cuaslui Creek westward to a point at least a mile beyond the Howard Canyon road, is underlain by strata so nearly horizontal as to preclude their containing very productive accumulations of petroleum. North and northwest of this region, however, especially near the axes of the Gato Ridge anticline and the anticline north of it, the indications are good for productive wells. The conditions for the accumulation of petroleum are also good along and just south of the axis of the Gato Ridge anticline in the vicinity of Cuaslui Creek and from this locality westward to the upper portion of Canada de los Coches. The same might be said of the immediate vicinity of the row of prominent knobs which extend in a straight line northwestward for 5 miles from a point about a mile north of Los Alamos, and possibly also, but in a less degree, for the territory between these knobs and the axis of the



ridge east of Figueroa Creek, as shown in Pl. VI, A (p. 46), and 30° SW. at the junction of Figueroa and Lisque creeks.

Conclusions regarding future development.—No indications of petroleum were noticed in proximity to this anticline, and it is almost certain that no productive wells will be developed on that part of it which lies within the Lompoc quadrangle, with the possible exception of a small area at its west end. There are good reasons for believing that the oil-bearing beds are absent from most of its northern flank, and if present under certain portions of its southern flank they lie at such a depth as to preclude their successful exploitation.

SUMMARY OF CONCLUSIONS REGARDING FUTURE DEVELOPMENT.

There can be no doubt that the region treated in this report is one of great promise. The structural and other conditions in general favor not only much more extensive development of the territory that has already been tested, but also the development of new fields. It must be borne in mind continually, however, that absolute determination, by work on the surface, of the possibilities of occurrence or nonoccurrence of oil in any one locality is not possible. The best that can be done is to calculate the degree of probability on the basis of a summation of surface indications and structural conditions.

The following is a list of the tracts that appear especially to invite testing with the drill. Most of them have been discussed in the foregoing pages:

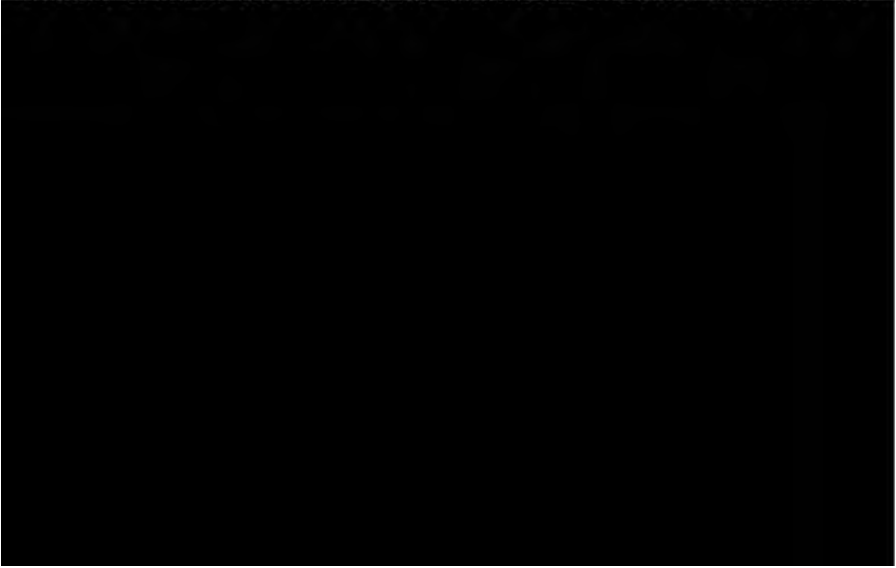
- North and northeast of Sisquoc post-office, along anticlines.
- General region east and west of Tepusquet Creek.
- Indefinite area west of Gary, about Fugler Point.
- Santa Rita Hills anticline.
- Near the coast north of Schumann Canyon.
- Schumann anticline in southeastern part of Casmalia Hills.
- Two anticlines on San Antonio terrace.
- Questionable region at mouth of Santa Maria Valley.
- Northeastern portion of Burton Mesa.
- Purisima Hills anticline, more especially the south side.
- Anticline at head of Santa Lucia Canyon.
- Region about Mount Solomon and related anticlines.
- Along Gato Ridge anticline and south of it between Canada de los Alisos and Canada de los Coches.
- Row of knobs extending 5 miles northwestward from a point about 1 mile north of Los Alamos and the territory between these knobs and the Gato Ridge anticline.
- Region northwest of the head of Howard Canyon, especially along the axis of the anticline south of Gary.
- Arroyo Grande field. (See pp. 107-108.)

DETAILS OF THE DEVELOPED TERRITORY.**DEFINITION OF FIELDS.**

In the following paragraphs are discussed the more important details regarding the structure, geology, oil zones, oil, and production in the areas in which development is well under way. These areas within the Lompoc and Guadalupe quadrangles fall naturally into two fields—the Santa Maria field and the Lompoc field. The former covers the whole territory between the Los Alamos and Santa Maria valleys, and the latter is used to designate the region south of the Los Alamos Valley. A third, the Arroyo Grande field, covering the territory north and northwest of the town of that name in San Luis Obispo County, lies to the north of the region mapped, but is briefly discussed. A note on the Huasna field, east of Arroyo Grande, is also appended.

SANTA MARIA FIELD.**CONTOUR MAP.****WHAT IT SHOWS.**

The contour map of the Santa Maria field (Pl. X) shows the boundaries of the different properties, the approximate location of all the wells, and the general structure of the field. The structure is indicated by contours showing the distance below sea level of a hypothetical horizon, zone, or bed, which just reaches sea level at the highest part of the axis of the Mount Solomon anticline. The contour interval is 100 feet. By means of this map the direction and amount of dip of the strata in the oil-bearing Monterey shale may be



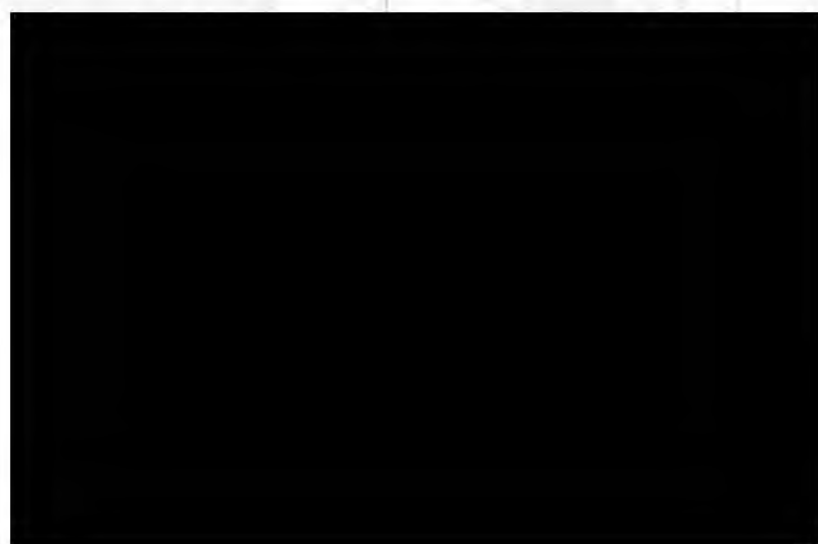


LEGEND

- ▲ Oil wells
- Water wells
- ◆ Abandoned
- Wells drilling
- Tanks



Compiled by Ralph Ann



the latter was followed. In the Fernando formation, which unconformably overlies the Monterey shale, it was natural to expect variance with the structure in the Monterey, but even here the surface evidence more often supported than contradicted the evidence obtained by the drill.

DIFFICULTIES OF PREPARATION.

After carefully plotting all the logs on a uniform scale it was found that the greatest obstacle to overcome in the preparation of the contour map was the correlation of strata from one well to another and from one part of the field to another. The difficulties of such correlations are doubtless familiar to anyone who has tried to work out the underground structure of any of the California fields. The Santa Maria field offers as much encouragement to successful study and mapping of the underlying oil-bearing formations as any other so far examined by the senior author, and so the effort has been made to delineate on the map all the details of structure furnished by the data available, and to supplement these details by showing for the untested areas what seem to be the most likely conditions of underground structure. It is very easy to make an ambiguous statement which will apply equally well to any conditions exposed by future development, no matter what they may be; but it is impossible to make an ambiguous map. However, it is deemed advisable to show the information in hand, incomplete as it is, on a map. Future development will doubtless add much to our knowledge of this field, and will show the inaccuracies of the contouring as here presented, but it is hoped that the benefits which may accrue to the operators from a knowledge of the general structure of the field will compensate in a measure for the errors in detail which are to be expected in a map based on data so incomplete.

THE WELLS.

AREAS DISCUSSED.

For convenience of discussion the proved portion of the Santa Maria field has been roughly divided into six areas, based largely on the geographic position of the wells. The following are the areas discussed: Hall-Hobbs-Rice ranch; Pinal-Fox-Hobbs; Pinal-Folsom-Santa Maria Oil and Gas-Escolle; Hartnell-Brookshire; Graciosa-Western Union; and eastern Western Union.

OIL ZONES.

Although in many instances detailed correlation from one well to another is impossible, four fairly well defined oil zones are believed to be recognizable in the Santa Maria field. Of these at least two are found in practically every part of the field, although all vary

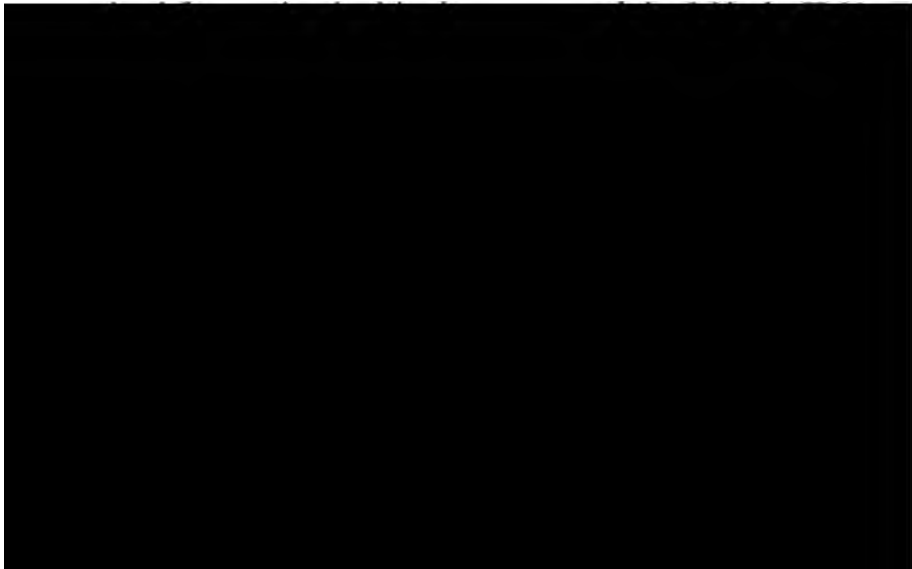
more or less in thickness, composition, and yield from well to well. The most persistent zone in that part of the field which is best developed at the present time is the second, or B zone. Above this in many of the wells is zone A; in others zone C is penetrated below it. The upper zone in the eastern group of Western Union wells, although above what is supposed to be the horizon of B, is probably considerably above the A zone of the northern part of the field, where it appears to have no correlative.

With the exception of the lowest zone in the wells in the eastern part of the field and of a few others mentioned in the detailed discussion of the local areas, the oil zones appear to represent fractured portions of the shales, the interstices in the breccia or possibly joint cracks in the beds being the reservoirs for the storage of the oil. The exceptions to the brecciated productive zones are apparently typical sands and gravels.

HALL-HOBBS RICE RANCH AREA.

LOCATION AND STRUCTURE.

The area here discussed comprises the California Coast, Meridian, Coblenz, Santa Maria Oil Company (Keyser), Hall & Hall, New Pennsylvania, Rice ranch, and Dome properties and the northeastern part of the Hobbs lease, and occupies the ridges and canyons which extend northward from the east end of the main Graciosa Ridge. The wells are located on the northwestern flank of the Mount Solomon anticline, at or immediately northwest of the territory, in which it swings from a northeastward to a southeastward trend. In addition to the main anticline there appear to be one or



one log reports "no shell" until the first oil zone is reached. Whenever "shell" is penetrated accumulations of gas or oil or both are generally encountered. The shale seems to be somewhat more sandy in this area than farther west or in the Graciosa-Western Union region.

Three oil zones are recognizable in the area under discussion, although practically all the strata from the top of the uppermost zone to the bottom of the lowest are more or less petroliferous at one point or another.

The first productive zone (A) is penetrated at a depth of 1,600 to 2,100 feet, varying according to the position of the well geographically and relatively to the axis of the anticline. Its top is from 550 to 700 feet above the top of zone B in this area. Zone A is productive for a distance in the wells of 20 to more than 500 feet. Of course this does not mean that the beds are productive in any one well for the whole distance of 500 feet, but that throughout the zone alternating barren and productive beds occur at such close and as a rule irregular intervals as to preclude their practical differentiation. The productive measures in this first zone consist both of hard fractured shale or "shell" and more or less porous sandy layers. In at least one of the wells the oil accumulates only under the hard "shell" layers. Zone A is the only one penetrated by some of the wells farthest away from the anticlinal axis. In these wells it appears to be much more petroliferous than in wells higher up on the fold.

The second oil zone (B) is from 550 to 700 feet below the top of zone A, and its upper limit is about 300 or 400 feet above the top of zone C, although it can hardly be said to be distinct from C in all the wells, so rich in oil are some of the intervening strata between them. True sands of medium grain, in addition to the productive hard shale, yield the oil in this zone.

The third oil zone (C) is encountered in some of the deeper wells nearest the axis of the main anticline. This zone has been penetrated for as much as 150 feet, the whole distance being very rich in petroleum. It is overlain by a considerable thickness of black shale, also more or less petroliferous, between which and the rich zone is a thin, hard "shell" layer. The oil-yielding rock is a true sand, coarse in places and even becoming pebbly toward its base in certain portions of the area. To the coarseness of the material is doubtless due the great productiveness of the zone.

PRODUCT.

The oil in the Hall-Hobbs-Rice ranch area runs from 26° to 29° Baumé and is dark brown in color. Gas accompanies the oil and also occurs isolated under some of the more impervious "shell" layers in the shale. No water is reported in any of the wells.

The production of the wells ranges from 300 to something over 2,000 barrels per day. Those wells which penetrate the lowest or C zone are the best producers. It is said that where a number of wells are located comparatively near together the production of each well is largely dependent on whether or not the adjacent wells are producing, a fluctuation of 50 per cent resulting from this cause in some instances.

PINAL-FOX-HOBBS AREA.

LOCATION AND STRUCTURE.

The area comprising the Fox lease, the southwestern part of the Hobbs lease, and the northeastern portion of the Pinal property, occupies the ridge and two adjacent canyons which extend northward from the central portion of Graciosa Ridge. The wells are located in an area of considerable structural disturbance caused by the development of two local anticlines on the northwestern flank of the main Mount Solomon anticline. These two minor flexures have been named after the companies under whose property they are best developed. Although the position assigned to them on the map is more or less hypothetical, the evidence in favor of it is fairly complete, and their location explains some of the variations in production of adjacent wells.

GEOLOGY OF THE WELLS.

Practically all the wells within this area start in the Monterey shale, and this is the prevailing formation to their bottoms. Certain portions of the shale are burnt to a brick-red color by the combustion of their hydrocarbon contents, the burnt shale being encountered as low as 330 feet in one of the wells. The burning has so hardened the



little consequence as regards production. The thickness of zone A in the wells ranges from 8 or 10 to nearly 150 feet, but several more or less important oil-bearing zones lie between this and the next lower (B) zone. The productive measures of zone A consist largely of brown shale, probably seamed or jointed in such a way as to afford a reservoir for the oil, although certain of the wells may obtain their product from fine-grained sands interstratified with the shale.

The second oil zone (B) is the most important one in this area, although it is underlain over at least a part of the area by zone C, which is apparently even more productive. The thickness of zone B is variable, but most of the wells penetrate from 50 to 150 feet of productive strata at this horizon. The oil-bearing beds are similar to those of zone A and appear to consist largely of hard shales, with some fine sands, although some excellent examples of a true siliceous sand are obtained in many of the wells. A hard limestone "shell" overlies zone B in one well.

The third oil zone (C) is penetrated by some of the deeper wells at a depth of about 300 to 400 feet below zone B. In one of the wells zone C appears to be missing, although a good flow of oil is reported from the same hole about 500 feet below where it should occur.

Water underlies oil-zone B in one of the wells and zone C in another. This occurrence of water below the oil, so common in most fields, is very rare in this one. Whether or not in the course of time water will follow up the oil in the productive zones is something that will be awaited with a great deal of interest. Some of the wells in the Santa Maria field have been stopped in the midst of productive strata for fear of encountering water farther down, but whether or not these fears were well founded has never been established.

PRODUCT.

The oil from this group of wells is of a dark-brown color and ranges in gravity from 24° to 28° Baumé, the lighter oil usually occurring in the wells nearest the main anticline; the average gravity is between 25° and 26°. Much gas is associated with the oil in all the wells.

The production of the individual wells ranges from 60 to 1,000 barrels per day, the latter amount coming from a hole very eccentric in its behavior, as shown by its yield of 200 barrels on some days and as high as 1,000 on others; the average daily production for this well is 300 barrels. With the eccentric well omitted, the maximum production is about 500 barrels per day. One well which produced 150 barrels from zones A and B added 350 barrels to its output when deepened to zone C.

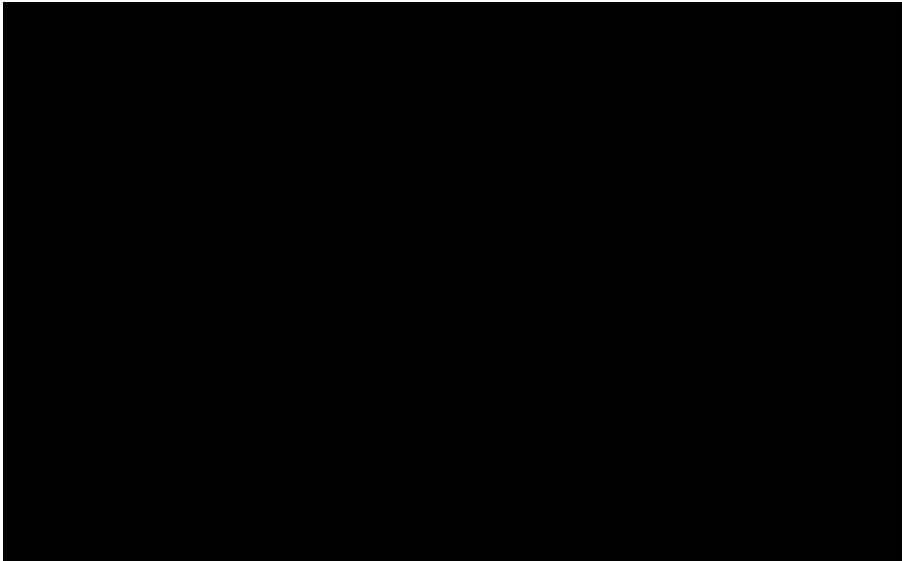
PINAL-FOLSOM-SANTA MARIA OIL AND GAS-ESCOLLE AREAS.

LOCATION AND STRUCTURE.

The area discussed in this section comprises the Folsom lease, the southern part of the Pinal property, the central and southern portion of the Santa Maria Oil and Gas lease, and the Escolle property of the Union Oil Company. The wells are located on the west end of Graciosa Ridge and in the canyons on its sides. The region is largely covered by the Fernando sandstone and conglomerate "cap rock," although the Monterey shale is exposed in the side canyons. The structure underlying this part of the field is comparatively simple so far as known, the main Mount Solomon anticline, which plunges northwestward through its center, being the only fold of consequence immediately affecting the area. The mapping of the anticline near Escolle well No. 3 is based entirely on the evidence offered by the well logs, which is at variance with the northwesterly dips in the Fernando in the vicinity of Escolle wells Nos. 2 and 3.

GEOLOGY OF THE WELLS.

Those wells which start in the Fernando remain in this formation for distances ranging from a few feet to nearly 300 feet, the strata penetrated being sand and conglomerate. In the region of Escolle well No. 1 and Folsom well No. 1 the Fernando appears to be exceptionally deep, extending nearly 300 feet below the surface, and to consist largely of conglomerate. One of the wells reports red conglomerate at 30 to 90 feet below the surface; whether this is burnt shale so hardened as to come out of the well in fragments of considerable size or whether it is true water-worn material is not known.





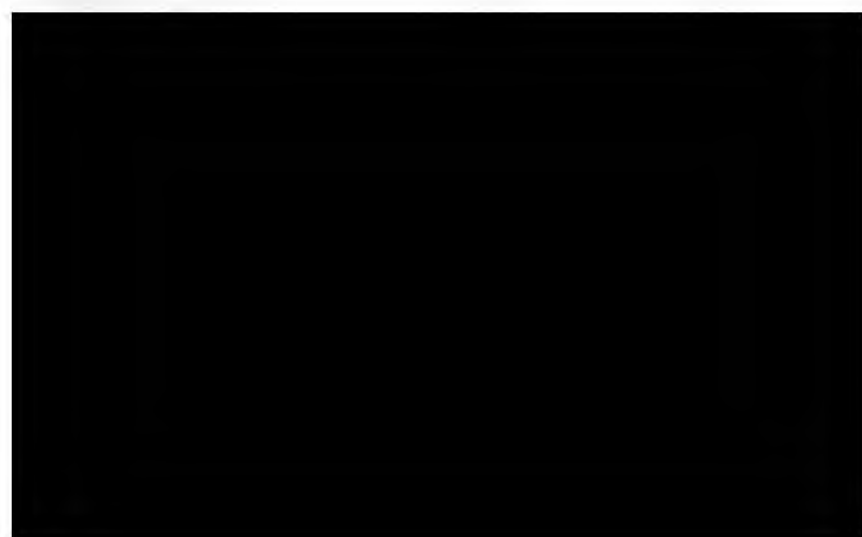
1. DARK-COLORED FOSSILIFEROUS BREa DEPOSIT OVERLYING MONTEREY SHALE.

Graciosa Ridge at Folsom well No. 3. Pinal camp on left and Santa Maria Valley in distance. Looking north. Photograph by Ralph Arnold.



2. SADDLE IN MONTEREY, FERNANDO, AND PLEISTOCENE BEDS.

Graciosa Ridge at Hartley well No. 1 near Orcutt. Pleistocene on left, Fernando (Pleistocene in upper right), Monterey (Miocene) in saddle. Looking east. Photograph by Ralph Arnold.



The first oil zone (A), which lies from 250 to 500 feet above zone B, is struck at depths ranging from 1,400 to 2,450 feet. Its thickness ranges from a few feet to about 50 feet; according to the logs it is lacking in some of the wells, the first oil being encountered in zone B. The oil-bearing strata in zone A are largely shale, which afford a reservoir for the oil, probably on account of their fractured condition. Beds of fine sand in this zone may also contain some of the petroleum.

The second oil zone (B), occurs at depths of 1,950 to 3,150 feet and is penetrated by all of the wells in this area. It ranges in thickness from nearly 50 to about 250 feet, in the wells; one of the wells, however, is said to encounter petroliferous beds intermittently from the top of zone B for a distance of 550 feet downward. The oil-bearing strata consist of alternating layers of hard shale and fine sandstone.

The third oil zone (C), occurs from 500 to 600 feet lower in the wells than zone B and consists of two parts, each from 25 to 50 feet thick, separated by a layer of shale of variable thickness; in one of the wells, however, the intervening shale is missing and the strata are richly impregnated with oil from the top of the zone for a distance of 250 feet downward, to a point where a 3-foot layer of water sand limits the productive zone. In practically all the wells in the field zone C is very rich, and nearly all the wells tapping it are fine producers.

PRODUCT.

The oil obtained in the area under discussion averages somewhat better than that in the area to the east, and has a gravity of 26° to 28° Baumé, with an average somewhere between 26° and 27°. As is common in other portions of the field, the gas pressure in most of the wells is high.

The production of the individual wells ranges from 100 to 2,700 barrels per day, the well yielding the latter amount being said to have had an initial daily output of 5,000 barrels for a short time. In one series of wells those down the dip are more productive than those nearer the axis of the anticline, the variation being at least partially accounted for by a thickening of the oil zone away from the axis.

HARTNELL-BROOKSHIRE AREA.

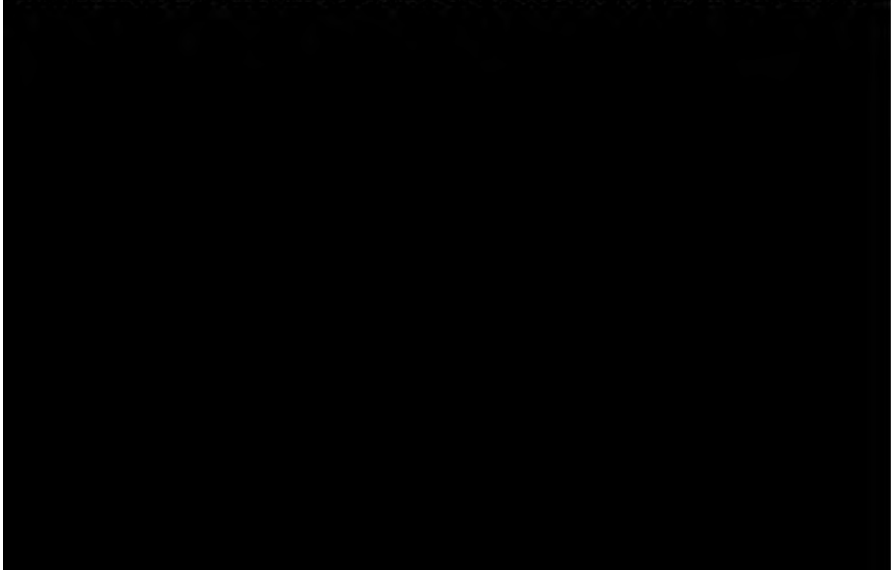
LOCATION AND STRUCTURE.

The area comprising the southern portion of the Hartnell tract and Brookshire property and the southeastern portion of the Radium lease is located on or adjacent to the ridge running northwestward from a point near the west end of Graciosa Ridge, and in the broad valley to the south. The major structural feature developed in the

beds underlying the area is a northwestward-plunging anticline which is here called the "Hartnell." There is both surface and underground evidence of its presence, but its exact location is, of course, only conjectural. As will be noticed on examining the map (Pl. X, p. 92) the northern flank of the anticline is much steeper than the southwestern, this fact apparently having a direct bearing on the productiveness of the wells penetrating this flank.

GEOLOGY OF THE WELLS.

The surface distribution of the formations in the immediate vicinity of the little swale on the ridge in which Brookshire wells Nos. 3 and 4 are situated is very interesting. The bottom of the swale is Monterey (Miocene) shale; unconformably overlying this on the south is fossiliferous Fernando (Pliocene) sandstone and conglomerate; immediately north of the swale is terrace-deposit (Pleistocene) sandstone. (See Pl. XI, B.) It has been suggested that such a condition is most easily explained by the presence of a fault through the swale, the downthrow being on the north. The logs of the wells in the immediate vicinity, however, offer evidence that such is not the case, but that the underlying Monterey strata, followed almost immediately north of the swale by fossiliferous Fernando beds, plunge steeply northward and are overlain unconformably by the low-dipping or practically horizontal terrace beds which are exposed on the ridge north of the swale. Some of the wells starting in the post-Monterey formations penetrate sand and gravel for a distance of more than 600 feet before entering the Monterey. Limestone, probably corresponding to the limy layers associated with fossiliferous beds at the base of the Fernando in the railroad cut north of Schumann, is reported as occur-



Between the first zone and the one that has been recognized as the second, or zone B, are one or more productive zones 2 to 15 feet thick. No two wells show the same sequence of these zones and they probably represent places of local fracturing.

The second oil zone (B) is thought to be fairly constant throughout the area. It consists of alternating barren and productive layers of shale, some of the productive layers being from a few feet to as much as 20 feet thick. Below the main or upper part of this zone are other productive layers, some at least 200 feet below zone B. The oil-bearing measures in these zones, as in zone A, are probably nothing more or less than fractured portions of the shale.

PRODUCT.

The oil from the wells in this area runs from 24° to 26° Baumé, and is dark brown in color with the exception of that from one of the wells, which is said to be a reddish emulsion of oil and water. All the wells show much gas, the best producers, especially, being under heavy pressure.

The production of the individual wells in this group ranges from an initial output of 12,000 barrels per day in one well to a daily average of 150 barrels in another. The following statement concerning the production of Hartnell well No. 1, the greatest producer in the California oil fields, has been kindly furnished by Mr. Orcutt, of the Union Oil Company:

Well (Hartnell No. 1) started to flow over derrick through 8½-inch and between this and 10-inch casing December 3, 1904. Gas pressure was very heavy, estimated at 400 pounds per square inch—was probably much higher, however. Oil was measured in an open ditch by use of a miner's-inch measuring box, and showed 31 miner's inches, or about 12,000 barrels per day. The flow continued for about sixty days and gradually weakened. September 1, 1905, the well was doing 3,069 barrels per day.

The oil was stored in earthen reservoirs, and the production to the above date is estimated at 1,500,000 barrels from this well alone. Up to August 15, 1906, the total production for the well was something over 2,000,000 barrels.

The gas accompanying the initial flow of oil was estimated at 4,000,000 cubic feet per day. After the well had been gotten under control it furnished gas for running 20 boilers for well-drilling rigs, and in addition supplied the town of Orcutt (population about 200) with gas for domestic purposes. At the present time it is still yielding a constant flow, which is used for many purposes in Orcutt.

GRACIOSA-WESTERN UNION AREA.

LOCATION AND STRUCTURE.

The wells at the northeast corner of the Graciosa and northwestern corner of the Western Union properties are located on the point of the ridge which runs southward for more than a mile from the main Graciosa ridge. The structure of the beds underlying the developed area is apparently simple, as they are on the southwestern flank of the hypothetical Newlove anticline. At least two minor

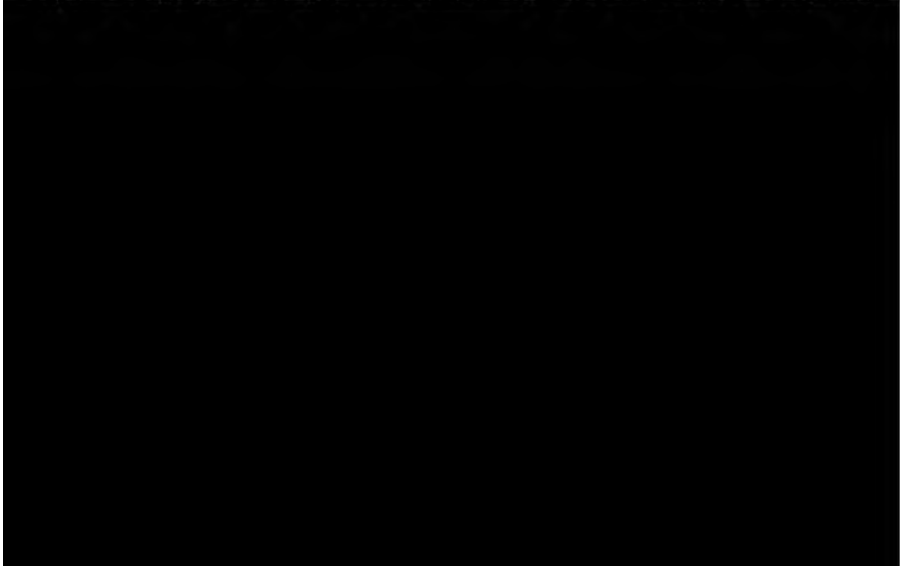
folds occur on this flank, one apparently passing through Western Union wells Nos. 21 and 22 and the other occurring from three-eighths to five-eighths of a mile farther northwest. The Newlove anticline as shown on the map is wholly hypothetical. It is the expression of the most plausible explanation of the relationship which is supposed to exist between the known Graciosa-Western Union and the eastern Western Union well areas. The surface evidence of the structure consists of a 10° SE. dip in the Fernando beds just north of the Graciosa wells, together with some more or less uncertain dips in the Monterey toward the head of the ridge, approximately parallel with which the anticline is supposed to run.

GEOLOGY OF THE WELLS.

The wells all start in the sands of the Fernando, penetrating this formation for 70 to 300 feet. No water is reported from this sand, but asphaltum is said to have been found at its base in one of the wells. From the base of the Fernando to the top of the main productive zone the formation consists of blue and brown shales with many hard "shell" layers, some beds of sticky shale, and rarely a little sandy material. Streaks of asphaltum are reported as occurring in the shale in some of the wells, and in others gas is present under some of the "shells."

The first oil zone (B of the northern part of the field) is reported from only one well, where it is nearly 200 feet thick and is encountered at a depth of about 2,075 feet. Gas is associated with the oil in this zone.

The second and important oil zone of this area (C) is struck at depths ranging from 2,670 to something more than 3,800 feet, and



owing to the lack of storage and transportation facilities, so that even had they been down long enough for a thorough test (which is hardly the case, inasmuch as nearly all have been finished since 1904) no definite conclusions could be drawn concerning their lasting properties.

EASTERN GROUP OF WESTERN UNION WELLS.

LOCATION AND STRUCTURE.

The eastern wells of the Western Union Company are located near the head of one of the branches of the broad valley which extends east-northeastward from Harris Canyon, at Blake, and are about 5 miles southeast of Orcutt. They are from one-half to three-fourths of a mile east of the west property line of the company and close to the north line. Slightly more than half a mile to the northeast of the wells is the axis of the Mount Solomon anticline, from the southwestern flank of which the wells derive their oil. The structure in the immediate vicinity of the wells, as indicated by the logs (see Pl. X, p. 92), is more or less complicated, the general strike of the beds apparently changing abruptly from northwest to southwest immediately northwest of the group. Furthermore, a local flexure with northeast-southwest strike immediately underlies the developed territory, and a pronounced anticline (here named the "Western Union") with a steep northeastern flank lies just to the south. There is no surface evidence of the northeast-southwest disturbance, but the Western Union anticline is plainly to be seen in the Fernando beds. The dip of the beds on the southwestern flank of this fold ranges at the surface from 15° at the west end of the hill south of the wells to 10° , and possibly much less, one-half mile to the southeast. The maximum northeasterly dip of 45° occurs south of well No. 18, but the slope rapidly decreases both to the northwest and southeast. As nearly as could be ascertained from the available data, the production of the wells in this group supports the anticlinal theory of the accumulation of petroleum—that is, for an equal thickness of productive zone the wells near the axis of the anticline in the local flexure are more productive than those farther away from it.

GEOLOGY OF THE WELLS.

The wells start in soil, but soon enter the clay, sand, and conglomerate layers of the Fernando, which is the surface formation in this part of the field. The Fernando beds are penetrated for 100 to 250 feet, varying with the location of the well, the wells on the north, as would be expected after an examination of the surface geology, passing through it in the shortest distance. Water and quicksand were encountered in at least two of the wells in the lower portion of the Fernando; in another, asphaltum occurs at the base of the formation. From the base of the Fernando to the first oil zone the wells penetrate

blue and brown shales, largely the latter, interstratified with hard "shell" layers, under some of which are accumulations of gas.

The first oil zone is struck at a depth of 1,200 to 1,800 feet, and ranges in thickness from 12 to 75 feet, although in some of the wells sands are encountered at intervals for at least 250 feet below the top of the first sand. The oil sand is as a rule rather fine grained and is accompanied both above and below by shale and rarely by shell. In some of the wells the oil zone appears to be practically continuous sand for its entire thickness; in others, alternating sand and shale layers furnish the oil.

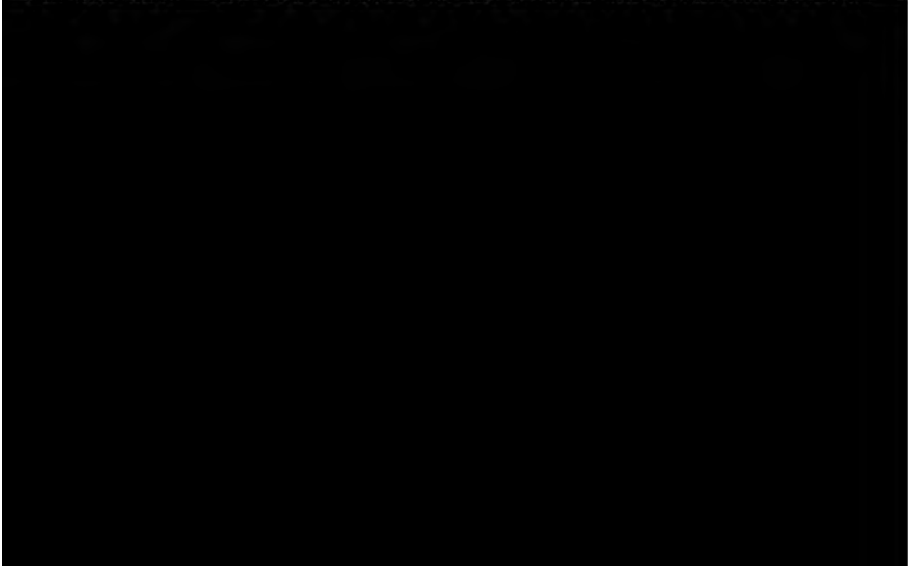
A second oil zone occurs about 1,200 feet below the first, the entire distance between the two being occupied by shale, with a few hard "shell" layers. Very little oil occurs at this horizon.

A third oil zone about 150 feet thick is penetrated 2,100 feet below the first, the formation between the second and third zones being practically all shale. Comparatively little oil was obtained from this zone in this part of the field, although it is thought to be the same as the one which is so productive in the Graciosa Western Union area only half a mile to the west. This may be accounted for by the general synclinal position of the eastern group between the Mount Solomon and hypothetical Newlove anticlines.

PRODUCT.

The oil in the first productive zone has an average gravity of about 19° Baumé and is very dark colored. Gas is associated with the oil, but no water has so far been reported from any of the wells.

The production of the wells in this group ranges from 5 to 154 barrels per day. The yield of some of the wells is fairly constant, show-



anticline is believed to be that shown on the map (Pl. I, in pocket); from the evidence offered by the logs of the Hill and Logan wells the axis of the anticline, so far as it affects the oil-bearing beds of this part of the field, might better be drawn through Hill well No. 1, extending westward and eastward (swinging to the north in both directions) to the points where the "surface" anticline passes from the Fernando to the Monterey. In either location, however, the anticline has a steeply dipping northern flank and a low-dipping and probably undulating southern flank.

A fault, clearly seen on the east side of Cebada Canyon and traced by deposits of asphaltum over portions of the rest of its course, extends from a point a short distance east of Cebada Canyon northwestward at least as far as the brea deposits near Wise & Denigan well No. 1. This is clearly a reverse fault in the Cebada Canyon region, supposed Monterey diatomaceous shale being thrust up on the north over Fernando sandstone which lies south of the line, the dip of the fault plane being about 30° toward the north. Mr. Orcutt suggests that this fault probably causes the difference in yield between Hill wells Nos. 2 and 3. The sand is struck about 700 feet lower in No. 3 than in No. 2, and is barren in the former but productive in the latter. The dip in the strata (if the anticline affecting the oil sands passes south of well No. 2) might account for the difference in depth of the oil sand in the two wells, but it alone would hardly account for the difference in saturation of the sands. It is quite possible that the fault (which theoretically emerges somewhere near Hill well No. 4) passes downward at such an angle as to cut the oil sand between Hill wells Nos. 2 and 3, throws the sand down on the north, and, while acting as an outlet for the oil in the sand for some distance on its northern or upper side, effectively seals up the truncated end of the same sand on its southern or lower side. This hypothesis assumes a downthrow on the north, a condition exactly opposite to that shown at the surface in Cebada Canyon. Alternate upthrow and downthrow on the same side of a single fault occurring at different times are not unusual in the Coast Ranges, so that such an explanation is not only possible but probable. To conform to the prevailing conditions the downthrow must have been on the north in pre-Fernando and on the south in Fernando or post-Fernando time.

The logs of the Wise & Denigan wells indicate a more or less local anticline in the Monterey. Its axis passes near well No. 2 of this group, and probably extends in an east-west direction parallel to the major lines of structure in the hills immediately to the north. This occurrence suggests the probable gentle folding of the Monterey in the region south of the Purisima Hills, in a manner similar to that which takes place under Burton Mesa farther west.

GEOLOGY.

GENERAL STATEMENT.

All the productive wells in the Lompoc field start in the Fernando formation and penetrate its clays, sandstones, and conglomerates for distances ranging from 45 to 800 feet. The great variation in the thickness of the Fernando in adjacent wells (the beds over much of the territory being nearly horizontal, implies great inequalities in the surface of the underlying Monterey shale, and this in turn signifies a profound unconformity between the two formations. Water is encountered in the Fernando at various depths in the different wells.

From the base of the Fernando to the top of the oil sand the wells pass through shale (largely "brown," according to the logs). Hard siliceous "shell" layers are encountered here and there in this shale, and in one well hard limy "shells" were struck at only 1,180 feet from the surface. These limy layers are abundant in the formation just above the oil zone, but are not found in most of the wells above this horizon.

Oil and gas are found in minor quantities in the shale at various depths, from 500 feet down in some of the wells in the northern part of the developed area, although such occurrences are not recorded for the wells in the southern part.

BURNT SHALE.

One of the most interesting features of the geology of the Monterey shale in this area is the evidence that combustion has taken place within it at certain points about 1,000 feet below the surface. Mr.



distance of 1,100 feet in one well. Either water sand, dry oil sand, or limy "shell" usually defines the base of the productive zone.

THE OIL.

Two grades of oil are struck in this field, one a black oil with a gravity of 18° to 24°, the other a brown to greenish oil of about 35° Baumé. The black oil is produced by most of the wells, the lighter variety coming only from the Logan well of the Los Alamos Oil and Development Company and the No. 3 Wise & Denigan well of the Union Oil Company. The relations of occurrence of the two grades are not known. One of the wells yields an emulsion of water and 20° oil, which is reddish brown in color as it comes from the well. This oil turns to the usual black color on separation of the water by settling.

PRODUCTION.

The production of the individual wells ranges from 100 to 1,000 barrels per day, the best producers averaging from 300 to 500 barrels. One of the wells which gave an initial output of 200 to 300 barrels at first, suddenly began flowing 1,000 barrels per day. This continued for a few days and then gradually fell off to 300 barrels, which it is still yielding. It is said that the wells, as a rule, are exceptionally steady producers, falling off but little in the two years since the field was first opened. Very few of the wells have been tried to their full capacity, so that it is probable that yields greater than those mentioned will be recorded when the field is fully tested.

ARROYO GRANDE FIELD.

LOCATION.

Drilling has recently shown that at least certain portions of the region north and northwest of Arroyo Grande, in the San Luis quadrangle, San Luis Obispo County, a short distance north of the area shown on Pl. I, are underlain by productive oil formations. The successful wells belong to the Tiber Oil Company, and are located on the west side of Price Canyon about 3 miles northeast of Pismo and 7 miles slightly east of south of San Luis Obispo. Although outside of the immediate area covered by this report the occurrence is so important in showing an extension of the Santa Maria district toward the northwest as to merit mention here.

GEOLOGY.

The geology of the San Luis quadrangle has been mapped and described by H. W. Fairbanks in the San Luis folio.^a According to

^aCopies of this folio, which is No. 101 in the series making up the Geologic Atlas of the United States, should be in the hands of every oil man or other person interested in the natural resources of this region; it may be obtained for 25 cents from the Director of the United States Geological Survey, Washington, D. C.

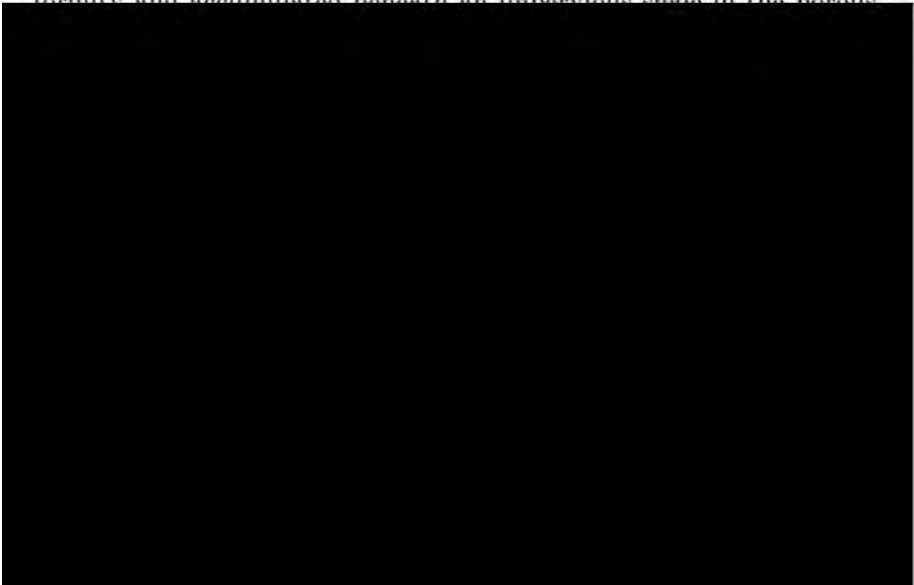
this work nearly all of the territory of the hills between San Luis Obispo Creek and the Arroyo Grande Valley, with the exception of a rather small area of Monterey volcanic ash, shale, and diatomaceous earth north of Pismo, is covered by the Pismo formation. This formation is composed of sandstone, some of which is asphaltic, and cherty diatomaceous beds, and is the equivalent of the lower part of the Fernando formation as described for the hills adjacent to the south side of the Santa Maria Valley. The Pismo is unconformably underlain by the Monterey shale, which outcrops on either side of it.

STRUCTURE.

According to Fairbanks, the Pismo area forms a low syncline, striking northwest and southeast, its flanks resting against the upturned Monterey.

OCCURRENCE OF THE OIL.

The oil is derived from a great thickness of productive sands which probably represent the base of the Pismo and which rest upon the upturned and more or less contorted shale of the Monterey. Its occurrence in beds occupying a synclinal position is worthy of note, as ordinarily synclines are not highly productive. The Monterey is the oil-bearing formation in the Santa Maria district, and it is the ultimate source of the oil in this field also. The migration of the oil probably took place along joint cracks in the shale, as was the case with the asphaltum in the Santa Maria and other fields. The oil, on reaching the upper limit of the shale passed across the plane of unconformity and accumulated beneath an impervious shale in the porous



by the oil-yielding Monterey. The surface evidence of such a condition is most conclusive. What effect local flexures either in the Monterey below the Pismo or in the Pismo itself will have on the production, only drilling will determine. According to Fairbanks's interpretation of the structure of the area, the depth at which the oil will be struck ought to decrease from the middle of the area toward both the northeast and southwest. The only well fully tested in the region yields 500 barrels of 14° oil per day, so that the prospects for the development of a good field are unusually bright.

As the Monterey shale underlying the Pismo of the Arroyo Grande field is continuous with the Monterey mapped in the Lompoc quadrangle northeast of the Santa Maria Valley, it is reasonable to suppose that there are considerable portions of this great belt of Monterey that will prove productive. The local structure is usually the determining factor in the accumulation of the petroleum, so that a thorough knowledge of this is essential to economical test drilling.

HUASNA FIELD.

The Huasna field lies east of the Arroyo Grande field and north of the Lompoc quadrangle. Prospect drilling is now going on in this region, but with what results the writers are not able to say. During a very hasty trip through this region in the summer of 1905 the senior writer noted great areas of Monterey shale, with some interbedded coarse granitic sandstones, in many places of considerable thickness. Such conditions are ideal for the accumulation of petroleum if the beds are not too sharply folded. This Monterey area is probably the continuation of that exposed in the northeastern part of the Lompoc quadrangle, and may connect the latter with the Monterey area east of Arroyo Grande and also with that covering the summit of the Santa Lucia Range a few miles east of San Luis Obispo. It is to be regretted that no maps adequate for showing the structure of the formations in the region east of the San Luis quadrangle and north of the Lompoc quadrangle are available. Without these it will be impossible to do for this region such detailed geologic and structural mapping as has already been done for the two quadrangles mentioned.

OIL OF THE SANTA MARIA DISTRICT.

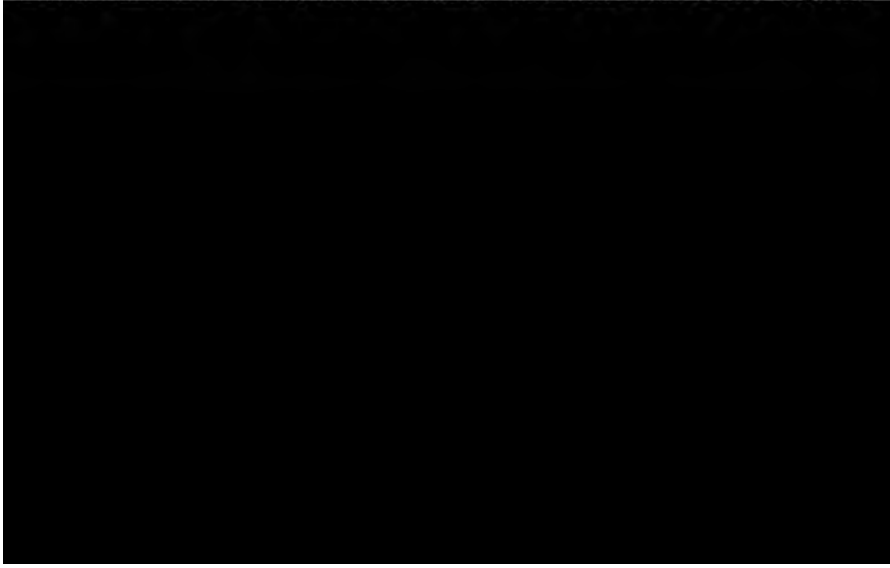
ORIGIN.

There is no doubt that the petroleum in the Santa Maria district is indigenous to the Monterey shale. Bitumen is a characteristic part of that formation throughout its wide extent over an area covering hundreds of square miles, and there is no other formation

but the Eocene shales in which it is characteristic, or in which it occurs in appreciable quantity except locally, although there are numerous formations which would be capable of storing oil if any had originated in them. Moreover, the bituminous Monterey shale of the Coast Ranges does not occur consistently above or below any one formation from which the oil could have been derived. It lies unconformably upon ancient metamorphic rocks; granite and other igneous rocks; Jurassic, Cretaceous, or early Tertiary sediments; or conformably over lower Miocene beds, according to local conditions; and it is either not covered by later deposits or is buried by sediments of various ages, in different places.

The decision is therefore unavoidable that some ingredients of the Monterey shale gave rise to the oil, and the question arises what these were. The organic composition of the strata making up this formation is discussed on pages 38-43, where a number of animal and plant forms that may have contributed to the oil are enumerated. The writers are strongly of the belief that the petroleum was derived largely from the minute organisms, especially the plant organisms (diatoms), which are present in such abundance in these shales. The chemists Peckham and Clarke believe that the nitrogen present in the California oil proves its origin from animal substance. But it is not necessary to consider that this petroleum originated entirely from either animal or vegetable matter; it is more probably the product of remains of both kinds combined, much of the nitrogenous material being furnished by animal tissue.

Other small organisms of a low order present in the Monterey shale besides the diatoms are Foraminifera and Radiolaria, both orders of marine animals. They became embedded in the mass of the organic



cause the relatively high percentage of nitrogen found in the California oils.

Fish skeletons are sometimes found in the shale, and flat impressions, large and small, that appear to be the scales of fish are abundant and very characteristic of certain portions of this formation, seeming to show that fish remains were in sufficient abundance to add at least something to the oil and to supply a portion of the nitrogen. On the other hand, these fossilized parts may have been originally separated from the tissue before they dropped to the ocean bottom or before being buried in the deposit, as by far the greater number of fish are believed to die violent deaths and to serve as food for larger fish or other animals.

Other animal organisms which were present and which may have contributed hydrocarbons and nitrogen were sponges, mollusks, and crustaceans—such as crabs and possibly ostracods. The impressions of seaweed occur in the shale but sparingly, probably because plants of this kind are restricted in habitat to shallower water than that in which it is believed the greater part of the Monterey was laid down, so that it is not probable that these plants have been large contributors to the material of the oil.

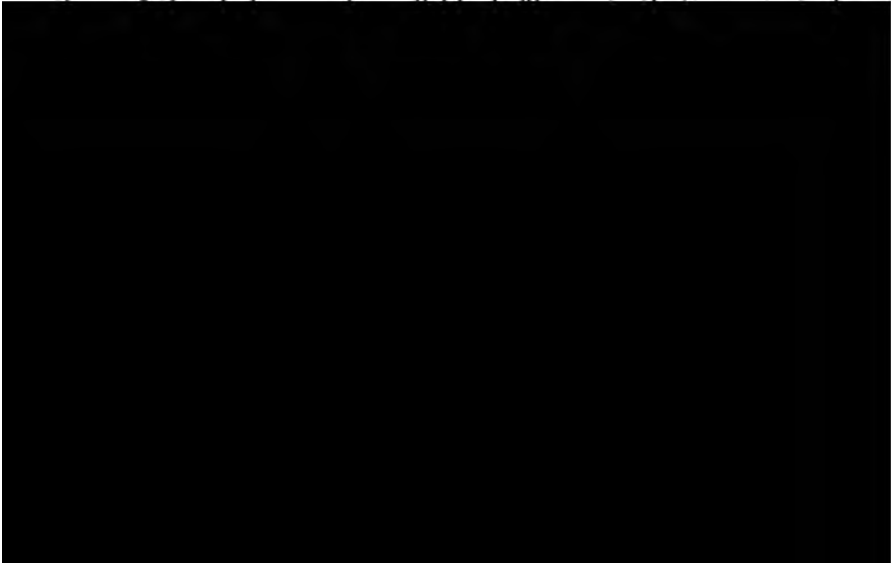
It is certain that there was a sufficiency of organic material included with the Monterey deposits to give rise to a vast quantity of petroleum, as is proved by a rough estimate based on low calculations of the amount of such material present. If the area covered by the Monterey formation in the Santa Maria district, including territory surely covered by it whether the formation now outcrops there or not, be taken as 800 square miles and the thickness of the formation as half a mile, the total volume of the deposit would be 400 cubic miles. These figures are low, especially in view of the fact that the average thickness and the areal extent of the formation were much greater when the oil began to be accumulated than at present. If we regard for the moment the diatoms alone to be the source of the oil, and only 1 per cent of the formation to be made up of these organisms, there would be 4 cubic miles of diatoms; and if we suppose further, simply as a rough guess, that these forms gave rise to an amount of petroleum equaling 1 per cent of their volume, we would have 1,000,000,000 barrels of oil as the amount distilled within the Monterey in this district, or more than thirty-three times the total production of oil in California for 1904, or eight times the production in the United States for the same year. According to Albert Mann, who has recently made an extensive study of diatoms, these plants when living secrete algal wax or oil in amounts varying from 0.75 per cent to as much as 4 per cent of their total volume. The amount of petroleum that might be derived from the diatoms is entirely unknown; but if the figure assumed hypothetically as

being 1 per cent is too liberal, it would seem that the low estimates of the amount of diatomaceous material present and the complete ignoring of the other important organic sources for oil in the shale, would still cause the estimate to be conservative.

In considering the question, What kind of organic material has a character most favorable for producing oil? the relative rate of putrefaction is important. Plants have the advantage in respect to their slower rate of decomposition. David White inclines to the view that plants are more favorable to the production of oil, largely for this reason. He says that putrefaction, which is largely a bacterial process, goes on more rapidly in animal tissue, while vegetable material has a tendency to turn into hydrocarbons. The slow decomposition of the protoplasm contents of the diatom frustule is especially significant. F. J. Keeley, of the Philadelphia Academy of Natural Sciences, says as follows in a letter:

The only point I can think of that might have any bearing on the question of the relation of diatoms to petroleum is the fact that the organic matter of diatoms does not appear to decompose and become dissipated quickly after death, as is the case with most low organisms. It is well known that diatoms kept in water will show the shrunken contents for years, and Ehrenberg noted the presence of such organic contents in old fossil diatoms from Hanover, while J. Brun reports a similar observation in a fossil deposit from Holland.

It is worthy of note that many of the round white diatom tests of the soft Monterey shale contain minute specks of black that appear like bituminous material derived in situ from the diatom. These specks, however, are present in but a small proportion of the tests and there is no proof that the black substance has not come from infiltration and deposition in the slight hollow of the shell. Thin



in the porous mass and they may have acted as preservatives of the organisms to some extent.

As regards the age of the oil, it is stated by F. W. Clarke^a that the process of formation of the oil from organic sources may not be slow, but, on the other hand, comparatively rapid. It is usually thought, however, that the process of distillation is slow and is continued during a long time. The petroleum in the Monterey may have been formed immediately after the deposit was laid down, or the production of it may be still in progress. There is evidence, however, in the presence of burnt shale in a Pleistocene deposit (see p. 52), in the old and eroded deposits of asphalt, and in the presence in certain asphalt deposits of the bones of extinct Pleistocene mammals^b which were caught in tar springs in Pleistocene time, that much of the oil at least was formed in the Monterey and disseminated to the surface a long time ago. The accumulation and dissemination of the oil has probably gone on continuously ever since its first formation, the two processes taking place simultaneously. There may be portions of the formation from which the hydrocarbon content has not yet been extracted in the form of oil, whereas other portions may no longer contain any of the oil in its original disseminated condition. The metamorphism that gave rise to the harder shales may have had the effect of driving out the oil more completely than it has been separated from the softer shale, and thus aided its accumulation, although this is conjectural.

The general conclusion is that in the Santa Maria district the organic material in the Monterey shale that may have acted as the source of the oil was without a doubt adequate in amount for the production of the vast quantity of petroleum now present, and that the forms included in greatest abundance, the diatoms, were the chief source, although animals and perhaps other plants also contributed largely.

PHYSICAL PROPERTIES.

GENERAL STATEMENT.

The Santa Maria district yields four distinct grades of petroleum, in addition to the heavy oil which flows from springs or collects as asphalt deposits. These petroleum vary widely in their physical and chemical properties and as a consequence are utilized in many different ways, the lighter oils usually for refining, the heavier for fuel, road dressing, etc.

The oil as it comes from the wells contains varying quantities of gas, often amounting to a considerable percentage. The two prod-

^a The data of geochemistry (In preparation for publication by the United States Geological Survey).

^b Bull. U. S. Geol. Survey No. 309, 1907, pp. 154-155.

ucts are usually separated at the wells, the gas being utilized for heat or directly for power and the oil being run into tanks. This tank oil still contains gas, most of which, however, gradually passes off on exposure to the air, with a consequent lowering of the gravity of the oil. Before transportation by steamer it is necessary to pass the oil through a partial refining process for the removal of the lighter, volatile, more dangerous constituents; this is done at present in the refineries at Port Harford and Gaviota.

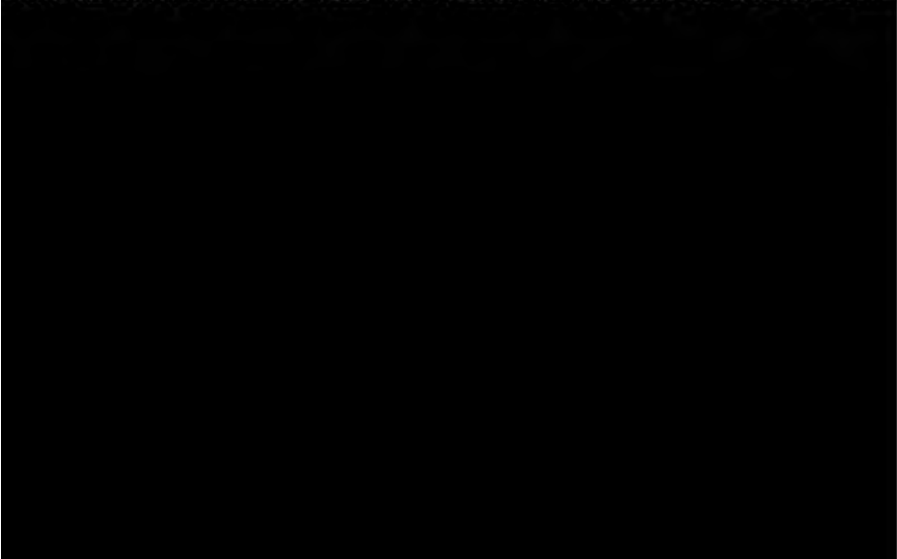
COLOR AND ODOR.

Nearly all of the oil in the Santa Maria district is dark brown in color. The exceptions are the black oil from the Arroyo Grande field, the reddish emulsion from one of the wells in the Hartnell-Brookshire area, and the brown to greenish oil found in certain of the wells in the Lompoc field. The heavier oil is the darker; the lighter grades show the greenish hues. The darkest oil in the Santa Maria field proper is the 19° petroleum from the wells in the eastern Western Union group. Some very dark oil is also said to come from the Lompoc field.

The heavy oil gives off an aroma not unlike some grades of lubricating oil, and, doubtless owing to the absence of hydrogen sulphide in solution, has little of the disagreeable odor common to that from some of the other California districts. In this district the lighter the oil, as a rule, the sharper and less agreeable is its odor.

GRAVITY.

The gravity of the oil ranges from 14° to about 35° Baumé. The heaviest oil (14°) comes from the Arroyo Grande field; 18° to 24° oil



those found in Bulletins Nos. 31 and 32 of the California State Mining Bureau. The analyses of Santa Maria oil contained in these bulletins were made by H. N. Cooper, and, together with those of oils from some of the other California districts, are copied in the table below.

The only definite information concerning the ultimate composition of the oil is contained in a table by P. W. Prutzman^a showing the incidental constituents of California crude oil. This author states that a Santa Maria oil of 17° (probably from the eastern group of Western Union wells) contained 0.43 per cent of nitrogen, no sulphur, and 8.37 per cent of asphaltene. The freedom of the Santa Maria oil from sulphur is one of its chief and valuable characteristics.

The following table^b contains analyses of four oils from the Santa Maria district, accompanied by analyses of twelve other California oils for purposes of comparison. The oil of analysis No. 3 in the table is the most characteristic of the average product of the Santa Maria field.

Following the table are distillation tests.

Chemical analyses of California petroleum.

[By H. N. Cooper, chemist. Samples collected by Marion Aubury, field assistant.]

No. of analysis.	Name of company.	County.	District.	Gravity.	Specific gravity of crude at 15° C. (about 60° F.).
1	Western Union Oil Co.	Santa Barbara	Western Union ..	° B. 20	0.9337
2	do.	do.	Carreaga	34.6	.8508
3	Pinal Oil Co.	do.	.....	27.6	.8882
4	Union Oil Co. of California ..	do.	Lompoc	16.2	.9574
5	Sea Cliff Oil Co.	do.	Summerland	14.9	.9065
6	King Refining Co.	Kern	Kern River field..	13	.9792
7	I. W. Shirley	Los Angeles	Middle field	16.5	.9559
8	Southern Pacific Oil Co.	Kern	McKittrick	18.5	.9425
9	Home Oil Co.	Los Angeles	Whittier	20.7	.9291
10	Brea Canyon Oil Co.	Orange	Fullerton	23	.9147
11	Los Angeles Pacific Rwy. Co. ..	Ventura	Santa Paula	27.3	.8900
12	Union Oil Co. of California ..	do.	Adams Canyon	28.9	.8814
13	California Oilfields (Limited) ..	Fresno	Coalinga	31.3	.8690
14	Home Oil Co.	do.	do.	34.1	.8530
15	Los Angeles Pacific Rwy. Co. ..	Ventura	Timber Canyon	35.1	.8481
16	Pacific Coast Oil Co.	Los Angeles	Pico Canyon	37.3	.8307

^a Bull. California State Mining Bureau No. 32, 1904, p. 224.

^b For a detailed description of the methods used in obtaining the data recorded in this table the reader is referred to Bull. California State Mining Bureau No. 31, p. 1; idem, No. 32, 1904, table opp. p. 230; or to Bull. U. S. Geol. Survey No. 309, 1907, pp. 205-208.

Chemical analyses of California petroleum—Continued.

No. of analysis.	Flash.	Viscosity.				Sulphur.	Calorific value of dry samples. ^a	Calorific values per cubic centimeter.
		At 15° C. (about 60° F.).		At 85° C. (185° F.).				
		Seconds.	Seconds divided by 27½ or water = 1.	Seconds.	Seconds divided by 27½ or water = 1.			
	°					Per cent.		
1	Below 15	1,060	38.40	77½	2.81	2.08	10,369	9,907
2	15	47½	1.72	29½	1.07	.60	10,825	9,203
3	Below 15	90	3.27	37½	1.36	1.56	10,543	9,364
4	21	Over 1,800	Over 65.00	227	8.23	4.43	10,258	9,822
5	Above 70	Over 1,800	Over 65.00	108	3.91	.44	10,348	10,001
6	Above 70	Over 1,800	Over 65.00	410	14.86	.....	.....	.....
7	Above 70	Over 1,800	Over 65.00	78	2.83	.85	10,437	9,976
8	32	1,100	39.85	54	1.96	.77	10,402	9,804
9	26	393	14.24	43	1.56	.....	.....	.....
10	Below 15	264	9.56	41½	1.50	.94	10,581	9,078
11	Below 15	61½	2.23	34½	1.24	.....	.....	.....
12	Below 15	162½	5.91	37	1.34	.48	10,647	9,384
13	Below 15	56	2.03	32½	1.18	.38	10,739	9,321
14	Below 15	28½	1.03	25½	.99	.06	10,568	9,040
15	Below 15	45½	1.66	31½	1.13	.....	.....	.....
16	Below 15	38½	1.40	29½	1.07	.28	11,141	9,322

No. of analysis.	Distillation.									
	Percentage.									
	Water.	Up to 100° C.	100°-150° C.	150°-200° C.	200°-250° C.	250°-300° C.	300° C. to asphalt.		Asphalt.	Loss or gain.
							A.	B.		
1	None.	0.9	6	10.5	9.3	11	39.5	.....	22	-0.8
2	None.	8.6	16	12	13.4	10.8	23	7.4	8	+.8
3	None.	8.2	17.7	12.1	9.4	9.1	29.7	.....	12	-1.8
4	7	1.3	3.9	5.5	7.7	18.3	34.3	.....	20.6	-1.4
5	.7	0	0	1	10	17.4	45.5	.....	23.5	-1.9
6	None.	0	0	0	0	22.5	37.5	6.9	31.1	-2
7	.8	0	0	0	7.6	13.9	40	14.5	21.8	-1.4
8	None.	0	4.2	8.9	8.7	20.2	27.5	7.5	22.5	-.5
9	None.	0	4.2	9.6	14	14.7	23	16.8	15.7	-2
10	None.	4.2	13.9	8.9	9.7	18.3	24.2	5	13.3	-2.5
11	None.	9.3	16.5	11.8	7.7	9.1	31.8	.....	13	-.8
12	None.	4	14.1	9.1	9.3	10.1	43	.....	9.8	-.6

Proximate analysis of a Santa Maria oil.^a

[Gravity, 16.9° Baumé.]

	Per cent.	Gravity (°B.).
DISTILLATION.		
Below 150° C.	1.0	.....
150° to 270° C.	24.0	36.5
Above 270° C.	31.1	.....
Asphalt, grade D.	41.9	.....
Loss.....	2.0	.....
CALCULATED ANALYSIS.		
Total gasoline.....	2.7	55
Kerosene.....	16.8	41
Middlings and lubricants.....	36.6	.....
Asphalt, by volume ^b	41.9	.....
Loss.....	2.0	.....

^a Prutzman, P. W., Bull. California State Mining Bureau, No. 32, 1904, Table 25.^b By weight (154 pounds per barrel), 46.2 per cent.

The following analyses of oils from the Santa Maria district have been kindly furnished by Prof. Edmond O'Neill, of the University of California, who writes concerning them as follows:

I do not know the exact locations of the wells from which these oils were derived, but they are from the first wells opened in the Santa Maria property [probably the Hartnell or the Santa Maria Oil and Gas Company lease]. There is very little difference in the character of oils from all this district, except in the proportion of light constituents and the corresponding percentage of sulphur. Most of these oils contain water, which seems to be either in a state of fine emulsion, or possibly in some feeble form of hydration—that is, frequently the water will not settle out on standing, even by centrifugalizing—nor will it all be driven off at a temperature of 100° Centigrade; but at a somewhat higher temperature it seems to be given off almost with explosive violence.

Analyses and tests of six samples of oil from wells near Santa Maria.

[Made by Edmond O'Neill.]

ANALYSES.

	No. 3.	No. 4.	No. 5.
Gravity at 15.5° C. (=60° F.)	0.891	0.894	0.893
Gravity in degrees Baumé	27.800	27.600	27.500
Flash point, open tester.....	(a)	(a)	(a)
Flash point, closed tester.....	(a)	(a)	(a)
Burning point, open tester.....	23° C. = 73.4° F.	22° C. = 71.6° F.	21° C. = 70° F.
Gasoline precipitate (asphaltine, etc.) per cent.	0.6	0.3	0.8
Sulphur.....do.....	1.57	1.59	1.56
Calorific value.....calories.....	10,260	10,363	10,229
Calorific value.....B. T. U.....	18,468	18,653	18,415
	No. 6.	No. 7.	No. 13.
Gravity at 15.5° C. (= 60° F.)	0.897	0.908	0.926
Gravity in degrees Baumé	26.800	24.800	21.670
Flash point, open tester.....	(a)	(a)	(a)
Flash point, closed tester.....	(a)	(a)	(a)
Burning point, open tester.....	21° C. = 68° F.	20° C. = 68° F.	24° C. = 75° F.
Gasoline precipitate (asphaltine, etc.) per cent.	0.7	1.6	3.0
Sulphur.....do.....	1.61	2.09	1.8
Calorific value.....calories.....	10,284	18,375	8,078
Calorific value.....B. T. U.....	18,512	18,676	14,541

^a Under 15° C. = 60° F.

Analyses and tests of six samples of oil from wells near Santa Maria—Continued.

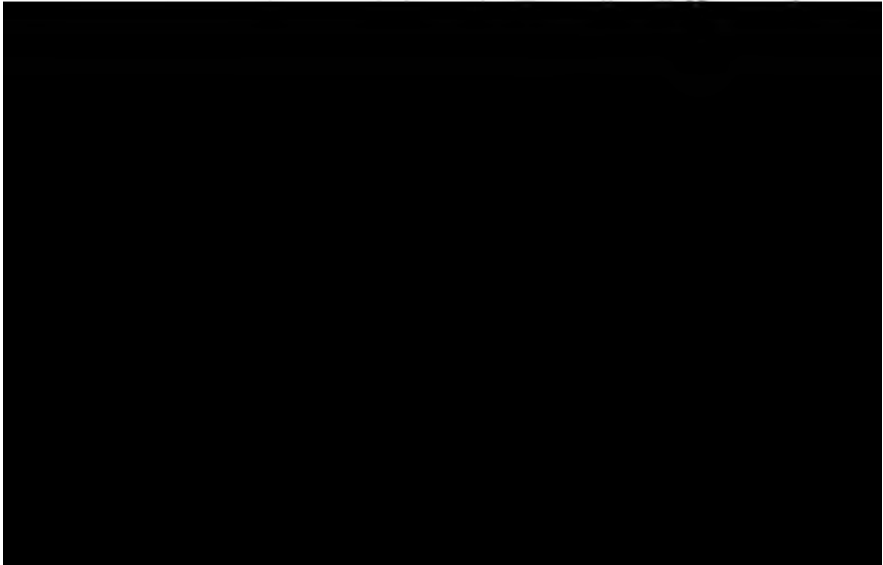
RESULTS OF DISTILLATION.

	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 13.
Water, per cent by volume..	1.2	0.2	Trace.	Trace.	Trace.	10.8
Benzines, boiling point under 150° C. (302° F.):						
Per cent.....	24.5	22.1	20.2	23.5	18.5	16.8
Gravity {Specific	.745	.740	.740	.752	.752	.742
Baumé	60°	61.°2	61.°2	52°	52°	60.°8
Kerosene, boiling point 150° C.-250° C. (302° F.-482° F.):						
Per cent.....	21.5	20.5	21.5	18.7	18.5	22.1
Gravity {Specific	.8345	.821	.818	.823	.822	.843
Baumé	39	41.8	42.5	41.4	41.4	37
Lubricants, boiling point 250° C.-350° C. (482° F.-662° F.):						
Per cent.....	19.0	22.8	19.2	20.0	25.5	17.2
Gravity {Specific	.905	.889	.898	.897	.895	.899
Baumé	25.3	28.2	26.6	26.6	27	26.4
Lubricants, boiling point above 350° C. (666° F.):						
Per cent.....	23.0	22.7	20.3	25.5	22.5	16.2
Gravity {Specific	.917	.905	.924	.917	.903	.906
Baumé	23.2	25.3	22	23.2	25.6	25
Asphaltum:						
Per cent.....	10.8	11.7	8.8	12.3	15.0	16.9

ASSOCIATED HYDROCARBONS.

NATURAL GAS.

Throughout the Santa Maria district wherever any oil has been found it is invariably accompanied by considerable quantities of natural gas; indeed, this form of hydrocarbon is somewhat more widely distributed than the oil, occurring in many places in the shale above the oil zones and in some wells which have yielded no petroleum. The pressure of the gas varies from zone to zone and from well to well. The



in detail by George H. Eldridge,* and are mentioned at various places throughout this bulletin; further discussion of them is therefore unnecessary.

TECHNOLOGY OF PRODUCTION AND UTILIZATION.

OIL COMPANIES OF THE SANTA MARIA DISTRICT.

The following is a statement of the oil operations in the Santa Maria district, compiled from all data available up to January 1, 1907:

Oil companies and wells in Santa Maria district.

Company.	Field.	Oil wells.			
		Produce-	Aban-	Drilling.	Total.
		tive.	doned.		
Anglo-Californian Oil Syndicate.....	Lompoc.....			1	1
Associated Oil Co.....	Arroyo Grande.....			1	1
Barca Oil Co.....	Lompoc.....		1		1
Brookshire Oil Co.....	Santa Maria.....	4	bl	1	6
California Coast Oil Co.....	do.....		1		1
California Coast Oil Co. (Union Oil Co.).....	do.....	3			3
California-Newlove Oil Co.....	Arroyo Grande.....			1	1
Casmalia Ranch Oil and Development Co.....	Santa Maria.....		1		1
Claremont Oil Co.....	do.....		bl	1	2
Coast Line Oil Co.....	Lompoc.....		1		1
Coblenz Oil Co.....	Santa Maria.....			1	1
Crown Oil Co.....	Arroyo Grande.....			1	1
Crystal Oil Co.....	do.....			1	1
Diamond Oil Co.....	Santa Maria.....				
Doane Oil Co.....	do.....	1		1	2
Graciosa Oil Co.....	do.....	6		2	8
Hall & Hall Oil Co.....	do.....			1	2
La Grande Oil Co.....	Arroyo Grande.....	1		1	1
Laguna Land Co.....	do.....			1	1
Lompoc Oil Developing Co.....	Lompoc.....				
Los Alamos Oil and Development Co.....	do.....	1	2		3
Las Flores Land and Oil Co.....	Santa Maria.....				
McNee Oil Co.....	Arroyo Grande.....			1	1
Meridian Oil Co.....	Santa Maria.....			1	1
National Oil and Transportation Co. (As-	do.....			1	1
sociated Oil Co.).....					
New Huasna Oil Co.....	Arroyo Grande.....			1	1
Oak Park Oil Co.....	do.....			1	1
Pennsylvania Oil Co.....	Santa Maria.....		1	1	2
Perpetual Oil Co.....	Arroyo Grande.....			1	1
Pacific Oil and Transportation Co. (Asso-	Santa Maria.....		1		1
ciated Oil Co.).....					
Palmier Oil Co.....	do.....	1			1
Pinall Oil Co.....	do.....	11		3	14
Radium Oil Co.....	do.....		1		1
Recruit Oil Co. (Escolle and Newhall).....	do.....		2	2	4
Rice Ranch Oil Co.....	do.....	2		1	3
Santa Barbara Oil Co.....	Santa Ynez.....			1	1
Santa Lucia Oil Co.....	Arroyo Grande.....			1	1
Santa Maria Oil Co. (Union Oil Co.).....	Santa Maria.....			2	3
Santa Maria Oil and Gas Co. (Union Oil Co.).....	do.....	4	1	3	8
Santa Ynez Valley Development Co.....	Santa Ynez.....				
Southern Pacific Co.....	Santa Maria.....			1	1
Standard Oil Co. (pipe lines, storage, etc.).....	do.....				
Stillwell Oil Co.....	do.....				
Syndicate Oil Co. (Union Oil Co.).....	do.....			1	1
The Oil Co.....	do.....		1		1
Tiber Oil Co.....	Arroyo Grande.....	1		2	3
Todos Santos Oil Co.....	Lompoc.....		1		1
Traders' Union Oil Co.....	Santa Maria.....		1		1
Union Oil Co.:.....					
Burton lease.....	Lompoc.....			1	1
Eaton lease.....	do.....	2	1	1	4
Folsom lease.....	Santa Maria.....	5		3	8

* The asphalt and bituminous rock deposits of the United States: Twenty-second Ann. Rept. U. S. Geol. Survey, part 5, 1901, pp. 209-452, pls. 25-58, figs. 1-52.

bl Water well.

Oil companies and wells in Santa Maria district—Continued.

Company.	Field.	Oil wells.			
		Producible.	Abandoned.	Drilling.	Total.
Union Oil Co.—Continued.					
Fox lease.....	Santa Maria.....	5		1	6
Hartnell lease.....	do.....	2	1	1	4
Hill lease.....	Lompoc.....	2	1	1	4
Hobbs lease.....	Santa Maria.....	8		2	10
Newlove.....	do.....			5	5
Wise & Denigan.....	Lompoc.....	8			8
Waldorf well.....	Santa Maria.....		1		1
Western Union Oil Co.....	do.....	26	3	2	31
Yakima Oil Co. (Lucas) (Associated Oil Co.).	do.....		1		1
		94	25	55	174

WELL DRILLING.

The wells in the Santa Maria district are among the deepest oil producers in the world, one of them reaching a depth of over 4,400 feet. Except at three or four wells, where rotary drills have been used to penetrate the soft sands and shales near the surface, all of the drilling has been done with the standard rig. The casing used ranges in diameter from 12 to 16 inches at the top down to 4½ inches, and in some wells, it is believed, even smaller, at the bottom. The cost of the deeper wells runs in general from \$12,000 to \$20,000, but several of the deepest are said to have cost even more than the latter figure.

Owing to the close texture of the shale, it is usually possible to carry the hole down for a considerable distance below the casing without danger of caving. Wherever the wells penetrate the soft

Production of crude petroleum in Santa Maria oil district, 1902—1906.^a

[Barrels of 42 gallons each.]

1902.....	99,283
1903.....	178,140
1904.....	1,367,174
1905.....	2,565,966
1906.....	4,906,513
	9,117,076

The estimated maximum capacity of the district January 1, 1907, is 40,400 barrels per day.

STORAGE CAPACITY.

The storage facilities of the district consist of steel and wooden tanks and open earthen reservoirs. The reservoirs are located only in the field and are used only temporarily or in cases of emergency. The total storage capacity of the district, not including the open reservoirs, is 1,464,000 barrels.

TRANSPORTATION FACILITIES.

The oil from the Santa Maria district is distributed by means of pipe lines, tank cars, and some of it eventually by tank steamers. The principal pipe lines of the district are four connecting the field with Port Harford and one running from the Western Union wells to Gaviota. The rail lines available are the Southern Pacific at Gaviota, Casmalia, and Betteravia, and the Pacific Coast at Carreaga and Orcutt. Tank steamers of the Associated, Standard, and Union oil companies take the product from Port Harford or Gaviota.

The following is a summary of the principal pipe lines in the district:

Pipe lines in Santa Maria oil district.

Company.	From—	To—	Distance.
			<i>Miles.</i>
Coast Oil Transport Co.....	Graciosa wells.....	Oil Port.....	34
Graciosa Oil Co.....	Wells.....	Casmalia.....	8
Los Alamos Oil and Development Co.....	do.....	Carreaga.....	
Pacific Oil and Transportation Co.....	Orcutt.....	Gaviota.....	51
Pinal and Brookshire oil companies.....	Wells.....	Graciosa station.....	2
Do.....	do.....	Betteravia.....	7
Standard Oil Co.....	Orcutt.....	Port Harford.....	32
Do.....	Western Union wells.....	Orcutt.....	7
Do.....	Hall, Dome, Pinal, and Brookshire wells.....	do.....	3
Standard Oil Co. (2 lines).....	Pacific Coast Oil Co.'s tanks.....	Port Harford.....	
Union Oil Co.....	Orcutt.....	do.....	32
Do.....	do.....	do.....	32
Do.....	Lompoc field.....	Orcutt.....	16
Do.....	Escolle and Santa Maria Oil and Gas Co.'s wells.....	do.....	3
Do.....	Fox, Hobbs, Folsom, and other wells.....	do.....	3
Do.....	Reservoirs Nos. 1, 2, and 3.....	do.....	4
Western Union Oil Co.....	Wells.....	Carreaga.....	4

^aCompiled from data furnished by the different operating companies.

REFINERIES.

The principal refineries utilizing the oil from the Santa Maria district are as follows:

California Petroleum Refineries, Limited.—The refinery of this newly organized company is now in course of erection at Oil Port, south of Port Harford. It is said that the initial capacity of this refinery will be about 7,000 barrels per day, and that all the usual products will be refined.

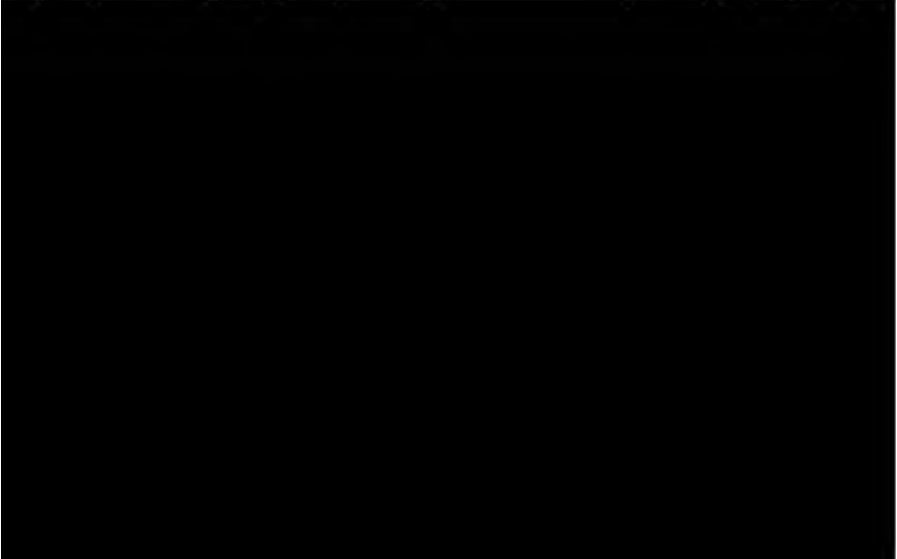
Pacific Oil Transportation Company.—The refinery of this company is located at Gaviota, and consists of nine stills with a capacity of 1,050 barrels of crude oil per day. The principal products are illuminants and fuel residue.

Standard Oil Company.—The plant of this company is located at Point Richmond, Contra Costa County, and is said to consist of 19 stills with a capacity of 5,000 barrels of crude oil and 4,000 barrels re-run per day. The products are illuminants, lubricants, and coke.

Union Oil Company of California.—The main refinery of this company is located at Oleum, Contra Costa County, and consists of a number of stills capable of producing illuminants, distillate, and asphalt.

UTILIZATION OF THE OIL.

Most of the oil from the Santa Maria district is refined, the lighter products being used for illuminants and for the direct generation of power in gas engines, and the heavier products and unrefined heavy oil for fuel, lubricants, road dressing, etc. With the exception of a very small amount used locally, all the oil is sent out of the district, the greater part of the product at present, it is believed, going to the



The formations involved in the geology of the district include the Franciscan (Jurassic?) sandstone, shale, glaucophane schist, jasper, and intruded serpentine; Knoxville (lower Cretaceous) conglomerate, sandstone, and shale; pre-Monterey (which may include both Cretaceous and older Tertiary) conglomerate, sandstone, and shale; Tejon (Eocene) sandstone, shale, and conglomerate; Vaqueros (lower Miocene) conglomerate, sandstone, and shale; Monterey (middle Miocene) diatomaceous and flinty shale, limestone, calcareous shale, and volcanic ash; Fernando (Miocene-Pliocene-Pleistocene) conglomerate, sandstone, and shale; and Quaternary gravel, sand, clay, and alluvium. The sedimentary formations of Tertiary and early Quaternary age have a combined maximum thickness of at least 13,200 feet.

A variety of igneous rocks of Cretaceous and Tertiary age, mostly intrusive, outcrop over small areas.

The Monterey shale (middle Miocene) is the original and chief oil-bearing formation, the petroleum having originated and remained in it in large quantities. Some has escaped by seepage and collected in the overlying Fernando formation or the Quaternary terrace deposits, or has been dissipated. The oil is supposed to accumulate in fractured zones and porous sands in the lower portion of the Monterey, where brittle shale predominates, anticlines furnishing the most favorable conditions for accumulation. The Monterey shale is in large part of organic origin, being especially rich in diatoms, and the oil is supposed to be a product of the plant and animal remains inclosed in it. The quantity of these remains originally deposited with this formation is sufficient to account for a vast amount of derived oil.

Two structural systems prevail in the district, the features in the northeastern portion striking northwest and southeast, those in the southern portion striking east and west, and those in the intervening region trending in a direction intermediate between the two. Few faults of importance were noted in the field. The productive territory lies in a region of more or less gentle folds in the central part of the area, most of the wells being located along or near anticlines.

The wells range in depth from 1,500 to more than 4,000 feet. In the Santa Maria and Lompoc fields they obtain oil from zones of fractured shale, and possibly in certain places from sandy layers in the lower portion of the Monterey formation. The production of the individual wells ranges from 5 to 3,000 barrels per day, the average being between 300 and 400 barrels. The oil ranges in gravity from 19° to 35° Baumé, the greater part of it being about 25° to 27°. In the Arroyo Grande field the oil comes from sandstone at the base of the Fernando and is of 14° gravity. There is in all these fields much undeveloped territory which offers great promise of being

highly productive. The conditions affecting the presence of oil have been discussed for individual areas and those places enumerated in which the conditions seem favorable for its accumulation.

There are 52 oil companies interested in the district; 11 of these own all the producing wells. Of the 174 wells in the district 94 are productive, 55 are drilling, and 25 are abandoned. The total production of the field up to January 1, 1907, was 9,117,076 barrels; the production for 1906 alone was 4,906,513 barrels.

PLATES XII TO XXVI.

PLATE XII.

TEJON (EOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

FIG. 1. *Cardium breweri* Gabb. Type. Right valve; altitude 61 mm. View of exterior. Pal. California, vol. 1, 1869, pl. 24, fig. 155. A common species in the Eocene of the Santa Ynez Mountains.

FIG. 2a. *Crassatellites collina* Conrad. U.S.N.M. 165312. Left valve; longitude 87 mm. View of exterior. San Julian ranch (4507). Characteristic of this horizon.

FIG. 2b. View of anterior end of same specimen.

FIG. 3. *Crassatellites collina* Conrad. U.S.N.M. 165312. Hinge. Same locality as fig. 2.

FIG. 4. *Pecten* (*Chlamys*) *yneziana* Arnold. U.S.N.M. 165313. Paratype. Altitude 52 mm. View of exterior. San Julian ranch (4507). Characteristic of this horizon.

FIG. 5a. *Ficus mamillatus* Gabb. U.S.N.M. 165319. Altitude 31 mm. View of back. North of Sudden (4518). Characteristic of this horizon.

FIG. 5b. View of top of same specimen.





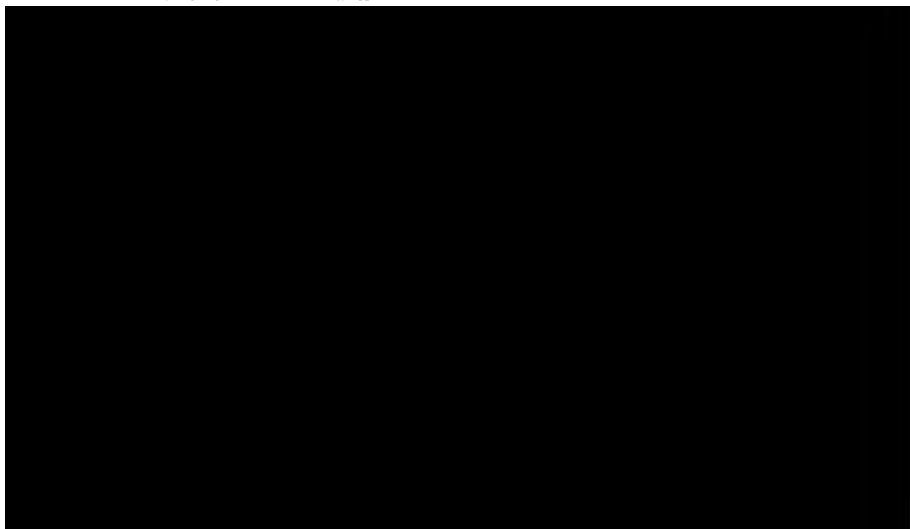
TEJON (EOCENE) FOSSILS.

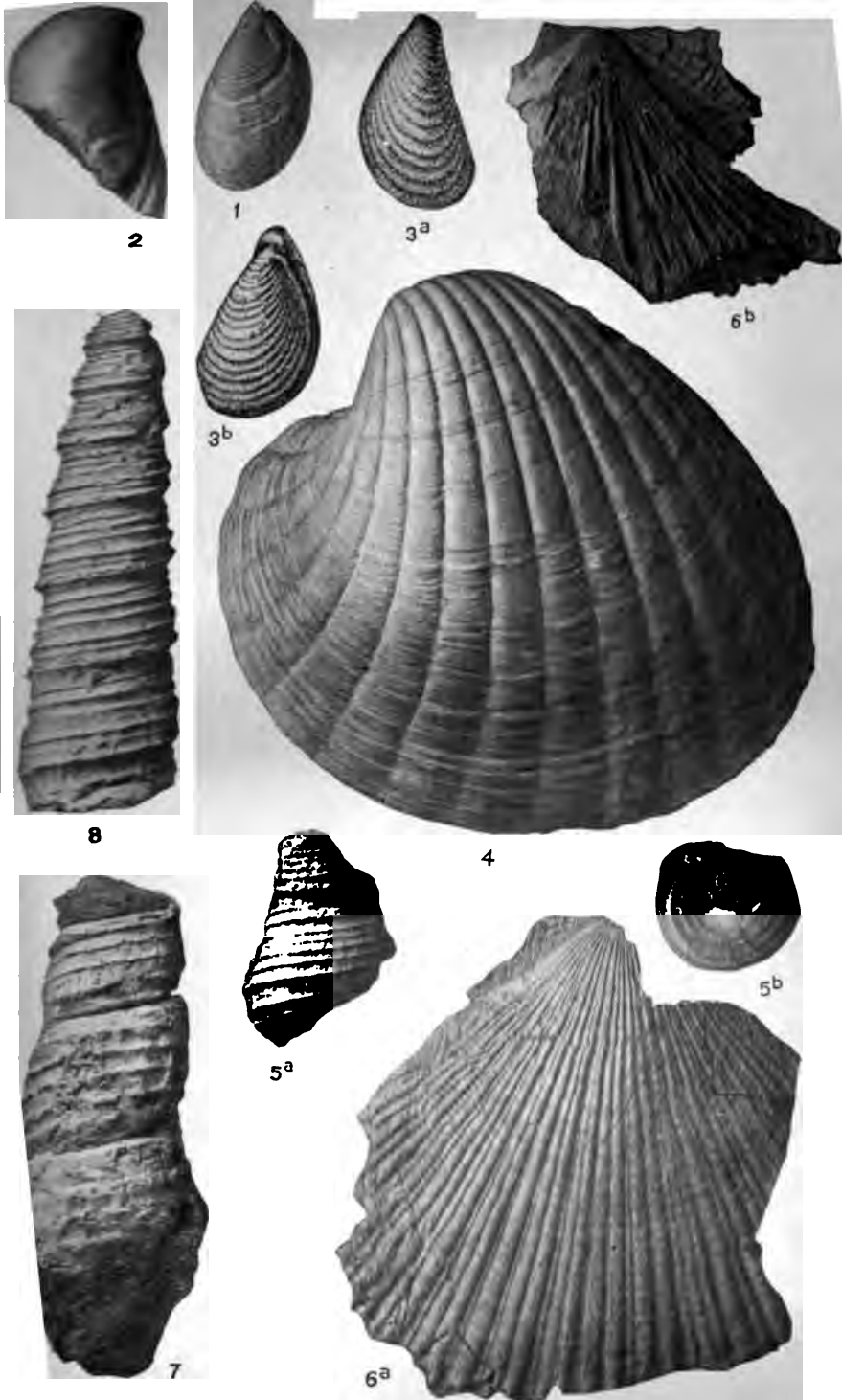
PLATE XIII.

KNOXVILLE (CRETACEOUS) AND TEJON (EOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

- FIG. 1. *Aucella piochii* Gabb. U.S.N.M. 30831. Right valve; altitude 25 mm. View of exterior. Knoxville (lower Cretaceous) formation, East Fork Tepusquet Creek (4173). Characteristic of the lower Cretaceous throughout the Coast Ranges.
- FIG. 2. *Aucella piochii* Gabb. U.S.N.M. 30831. Left valve; altitude 15 mm. View of exterior, $\times 2$. Same locality and horizon as fig. 1.
- FIG. 3a. *Aucella piochii* Gabb. Left valve; altitude 27 mm. View of exterior. Bull. U. S. Geol. Survey No. 133, 1895, pl. 4, fig. 6.
- FIG. 3b. Exterior of right valve of same specimen. Op. cit., pl. 4, fig. 7.
- FIG. 4. *Venericardia planicosta* Lamarck, U.S.N.M. 164973. Left valve; longitude 84 mm. Eocene, Little Falls, Wash. This is the most widespread and characteristic Eocene species in the world.
- FIG. 5a. *Turritella (martinezensis)* Gabb var. ? *lompocensis* Arnold. Paratype. Altitude of fragment, 30 mm. Back view. Same locality as fig. 8.
- FIG. 5b. Basal view of same specimen.
- FIG. 6a. *Pecten (Chlamys) yneziana* Arnold. U.S.N.M. 165313. Type. Right valve; altitude 64 mm. View of exterior. San Julian ranch (4507). Characteristic of this horizon.





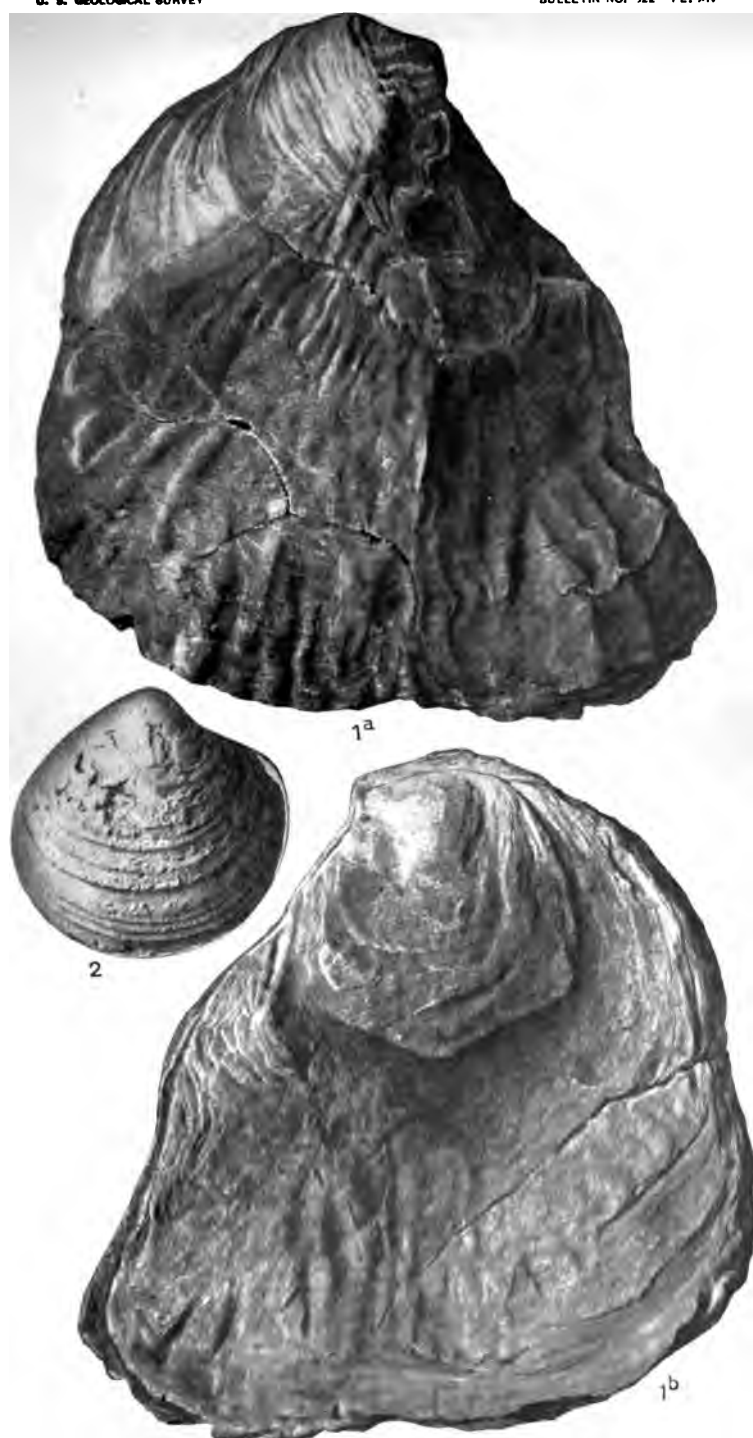
KNOXVILLE (CRETACEOUS), AND TEJON (EOCENE), FOSSILS.

PLATE XIV.

TEJON (EOCENE) PELECYPODA.

(Unless otherwise indicated all figures are natural size.)

- FIG. 1a. *Ostrea idriaensis* Gabb. U.S.N.M. 165318. Left valve; altitude 114 mm.
View of exterior. North of Sudden (4518). Characteristic of this horizon.
- FIG. 1b. View of exterior of right valve of same specimen.
- FIG. 2. *Phacoides cumulata* Gabb. U.S.N.M. 165328. Right valve; altitude 10 mm.
View of exterior, $\times 4$. Three miles north of Sudden (4518); also known from type locality of Tejon formation.



TEJON, EOCENE, PELECYPODA

PLATE XV.

VAQUEROS (LOWER MIOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

FIG. 1a. *Purpura vaquerosensis* Arnold. Collection of Delos Arnold. Type. Altitude 100mm Aperture view. Lynchs Mountain, Monterey County, Cal.

FIG. 1b. Back view of same specimen.

FIG. 2. *Modiolus yneziana* Arnold. U.S.N.M. 165324. Type. Right valve; altitude 31 mm. View of exterior, $\times 2$. San Julian ranch (4504). Characteristic of this horizon.



VAQUEROS (LOWER MIOCENE) FOSSILS.

PLATE XVI.

VAQUEROS (LOWER MIOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

- FIG. 1. *Pecten* (*Lyropecten*) *magnolia* Conrad. U.S.N.M. 165317. Right valve; altitude 155 mm. View of exterior, $\times \frac{1}{2}$. San Julian ranch. A characteristic Vaqueros species.
- FIG. 2. *Ostrea* *aldridgei* Arnold. U.S.N.M. 165307. Left valve; altitude 100 mm. View of exterior. Mouth of Ballard Canyon, 2 miles south of Santa Ynez (4478). Characteristic of this horizon.
- FIG. 3. *Turritella* *ineziana* Conrad. U.S.N.M. 165321. Altitude 120 mm. View of side. Ten miles west of Santa Ynez (4514). Characteristic of this horizon throughout the Coast Ranges.



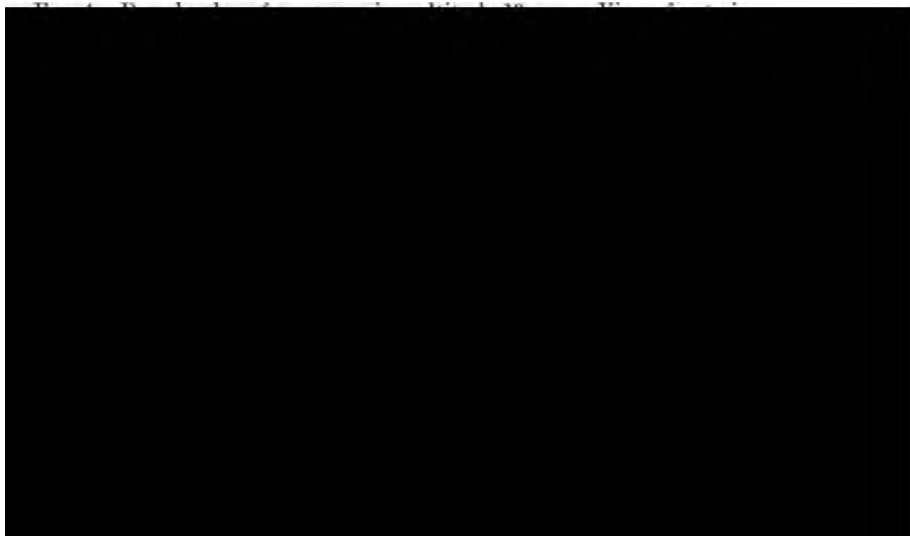
VAQUEROS (LOWER MIOCENE) FOSSILS.

PLATE XVII.

VAQUEROS (LOWER MIOCENE) PELECYPODA AND BRACHIOPODA.

(Unless otherwise indicated all figures are natural size.)

- FIG. 1. *Pecten* (*Pecten*) *vanvlecki* Arnold. U.S.N.M. 165305. Type. Right valve; altitude 64 mm. View of exterior. Mouth of Ballard Canyon, 2 miles south of Santa Ynez (4478). Characteristic of this horizon.
- FIG. 2. *Pecten* (*Pecten*) *vanvlecki* Arnold. U.S.N.M. 165306. Paratype. Left valve; altitude 72 mm. View of exterior. Mouth of Ballard Canyon, 2 miles south of Santa Ynez (4478). Characteristic of this horizon.
- FIG. 3. *Pecten* (*Chlamys*) *sespeensis* var. *hydei* Arnold. U.S.N.M. 165308. Left valve; altitude 60 mm. View of exterior. Mouth of Ballard Canyon, 2 miles south of Santa Ynez (4478). Characteristic of this horizon.
- FIG. 4a. *Terebratalia kennedyi* Dall. U.S.N.M. 165325. Type. Ventral valve; altitude 26 mm. View of exterior. Lime quarry 5 miles southwest of Lompoc (4521). Characteristic of this horizon.
- FIG. 4b. Dorsal valve of same species; altitude of fragment 18 mm. View of exterior.





2



4^a



4^c



VAQUEROS LOWER MIOCENE; PELECYPODA AND BRACHIOPODA.

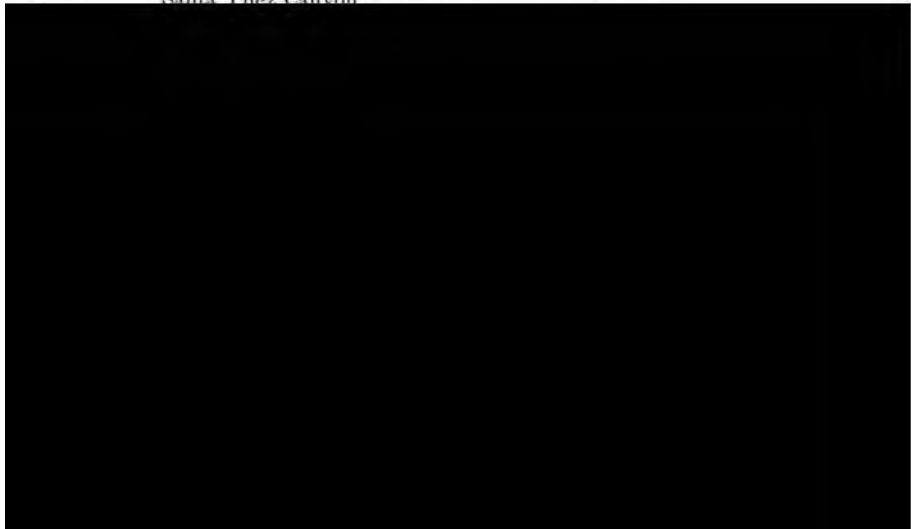
PLATE XVIII.

VAQUEROS (LOWER MIOCENE) PELECYPODA.

(Unless otherwise indicated all figures are one-half natural size.)

- FIG. 1. *Pecten (Lyropecten) crassicardo* Conrad. U.S.N.M. 164967. Exterior of valve, showing characteristic sculpture; altitude 90 mm. Ojai Valley, Ventura County, Cal. This species ranges throughout the Miocene, being commoner in the lower part in southern California, in the upper part in central California.
- FIG. 2. *Pecten (Amusium) lompocensis* Arnold. Collection of California Academy of Sciences. Holotype. Mold of interior of left valve; altitude 105 mm. Four miles south of Lompoc.
- FIG. 3. *Pecten (Amusium) lompocensis* Arnold. U.S.N.M. 164852. Paratype. Interior of a portion of left valve; altitude 90 mm. Ojai Valley, Ventura County, Cal.
- FIG. 4. *Pecten (Amusium) lompocensis* Arnold. Collection of California Academy of Sciences. Paratype. Imperfect mold of interior of right valve; hinge line 42 mm. Same locality as fig. 2.
- FIG. 5. *Pecten (Lyropecten) bowersi* Arnold. Collection of University of California. Type. Exterior of slightly imperfect right valve; altitude 150 mm.

Santa Ynez Canyon





1



4

6b



2



6a



5



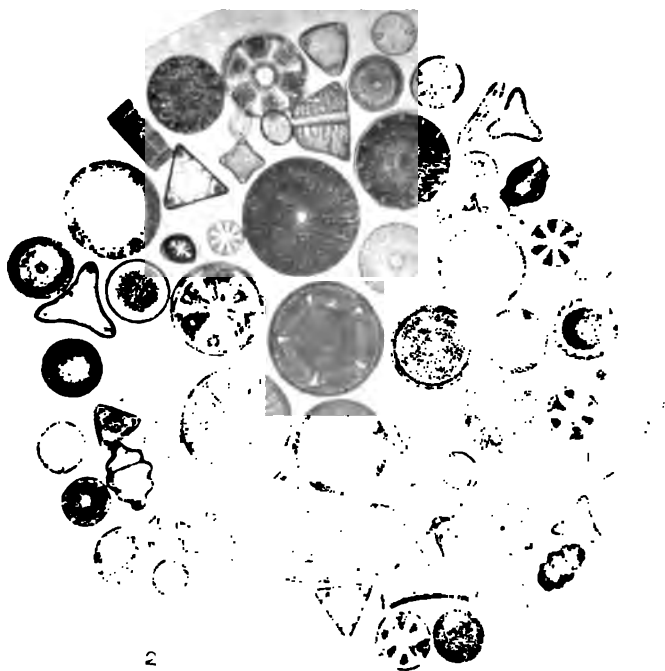
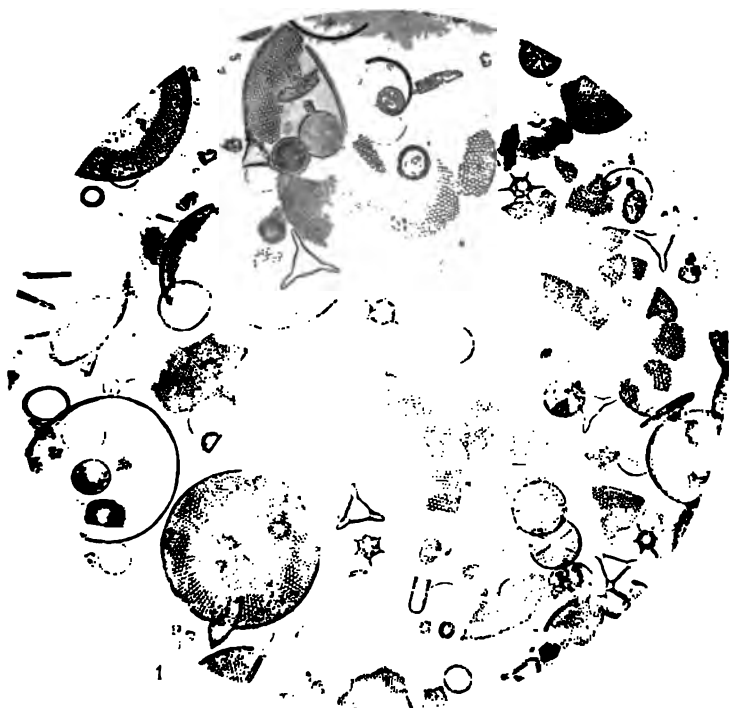
3

VAQUEROS (LOWER MIOCENE) PELECYPODA.

PLATE XIX.

MONTEREY (MIDDLE MIOCENE) DIATOMS.

- FIG. 1. Photomicrograph of slide of partially cleaned diatomaceous shale material from the Lompoc quadrangle, $\times 100$. All the larger individuals and fragments are *Coscinodiscus oculus iridis* Ehrenberg.
- FIG. 2. Photomicrograph of slide of diatoms from the Monterey shale at Santa Monica, Los Angeles County, Cal , $\times 60$. Nearly all the species shown on this slide occur in the diatomaceous deposits in the Santa Maria district.



MONTEREY, MIDDLE MIOCENE DIATOMS.

PLATE XX.

MONTEREY (MIDDLE MIOCENE) DIATOMS.

FIG. 1a. *Actinoptychus undulatus* Ehrenberg.

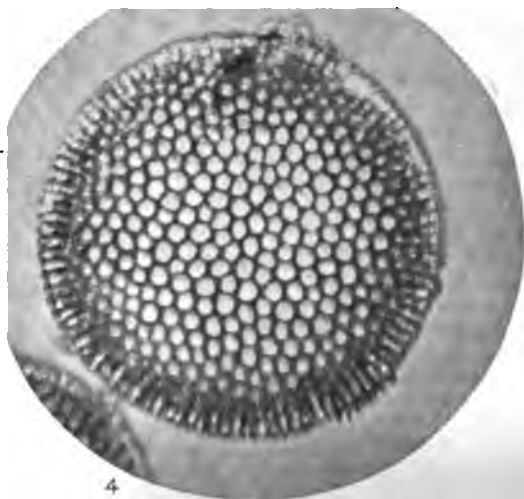
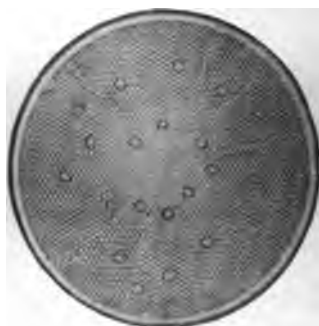
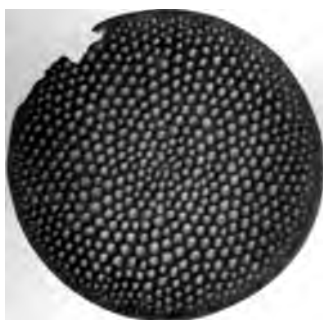
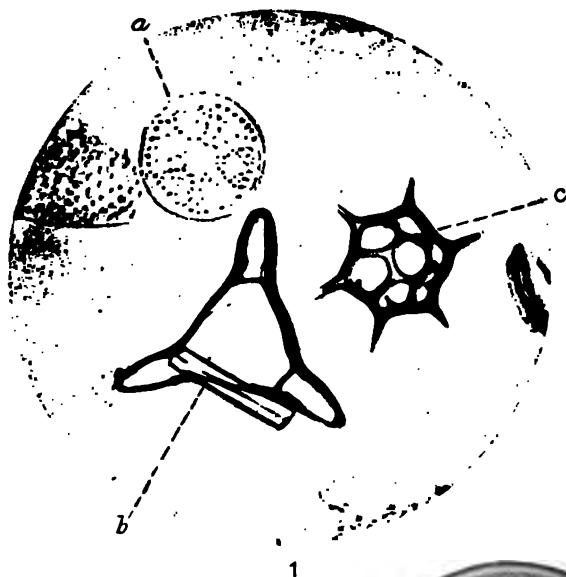
FIG. 1b. *Lithodesmium cornigerum* Brun.

FIG. 1c. *Dictyocha gracilis* (not a diatom; nature unknown). Enlargement to 1,000 diameters of a portion of the slide shown in Pl. XIX, fig. 1.

FIG. 2. *Coscinodiscus obscurus* A. S., $\times 1,000$. From the Monterey shale of the Santa Maria district.

FIG. 3. *Coscinodiscus subtilis* Ehrenberg, $\times 1,000$. From the Monterey shale of the Santa Maria district.

FIG. 4. *Coscinodiscus robustus* Grev., $\times 1,000$. From the Monterey shale of the Santa Maria district.



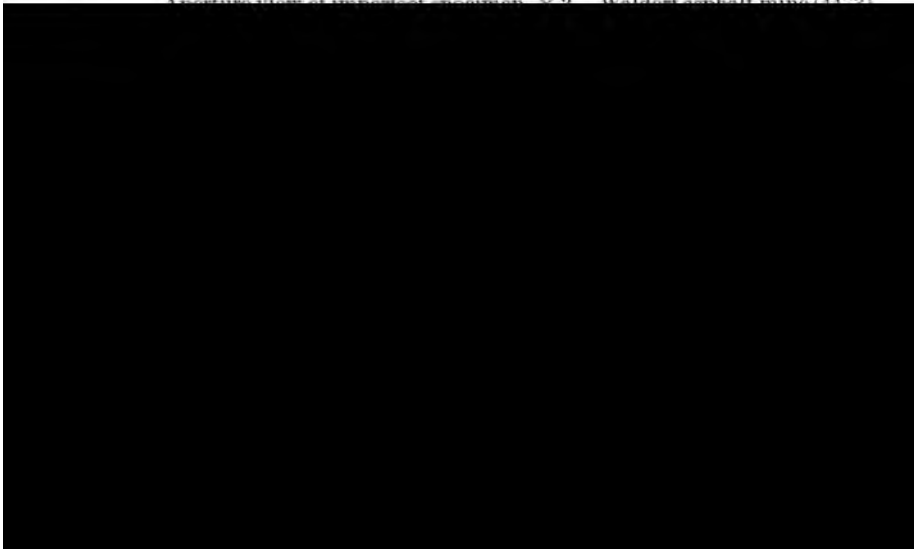
MONTEREY (MIDDLE MIOCENE). DIATOMS.

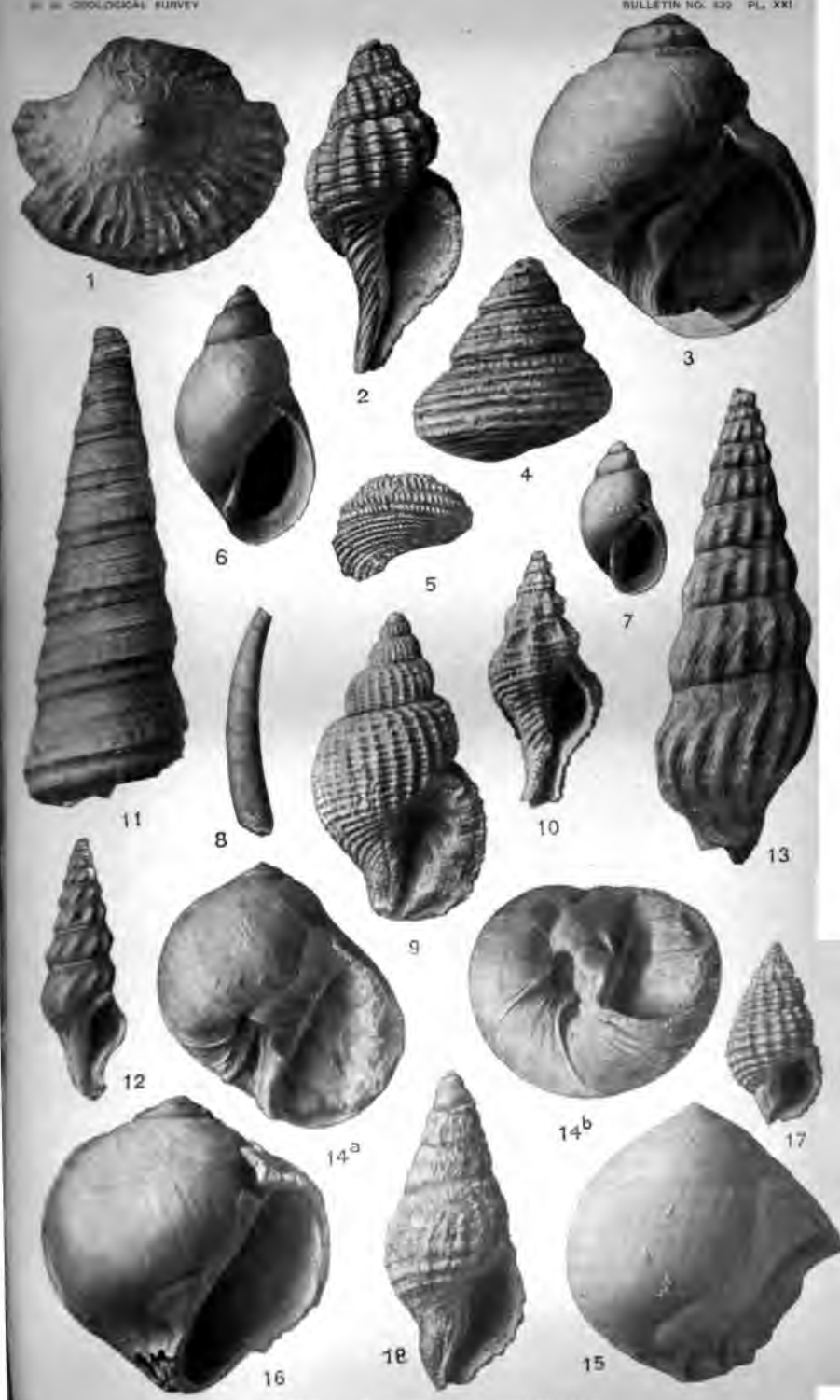
PLATE XXI.

FERNANDO (PLIOCENE) GASTEROPODA.

(Unless otherwise indicated figures are natural size.)

- FIG. 1. *Trochita radians* Lamarck. U.S.N.M. 165310. Maximum diameter of fragment 20 mm. View of top, $\times 2$. Fugler Point asphalt mine, near Gary (4475). Characteristic of the upper Miocene and lower Pliocene of this region.
- FIG. 2. *Priene oregonensis* Redfield (young). U.S.N.M. 165262. Altitude 46 mm. Aperture view. Waldorf asphalt mine (4473). Also known recent.
- FIG. 3. *Lunatia lewisi* Gould. U.S.N.M. 165264. Young specimen; altitude 23 mm. Aperture view, $\times 2$. Waldorf asphalt mine (4473). Also known recent.
- FIG. 4. *Thalotia caffea* Gabb. U.S.N.M. 165298. Latitude 29 mm. Back view. Fugler Point asphalt mine, near Gary (4475). Also known recent.
- FIG. 5. *Thalotia caffea* Gabb. U.S.N.M. 165297. Latitude of fragment 21 mm. View of side of fragment, slightly tilted up. Same locality as fig. 4.
- FIG. 6. *Lymnæa alamosensis* Arnold. U.S.N.M. 165426. Type. Altitude 6 mm. Aperture view, $\times 6$. Fresh-water beds, 1 mile southeast of bench mark 425, Los Alamos Valley.
- FIG. 7. *Lymnæa alamosensis* Arnold. U.S.N.M. 165426. Young specimen; altitude 3.5 mm. Same locality as fig. 6.
- FIG. 8. *Cadulus fusiformis* Sharp and Pilsbry. U.S.N.M. 165267. Longitude 10 mm. Side view, $\times 3$. Waldorf asphalt mine (4473). Known also recent.
- FIG. 9. *Cancellaria crawfordiana* Dall var. *fugleri* Arnold. U.S.N.M. 165322. Type. Altitude 22.5 mm. Aperture view, $\times 2$. Fugler Point asphalt mine, near Gary (4475). Characteristic of this horizon.
- FIG. 10. *Ocenebra micheli* Ford var. *waldorfensis* Arnold. U.S.N.M. 165261. Type. Altitude 11 mm. Aperture view, $\times 3$. Waldorf asphalt mine (4473).
- FIG. 11. *Turritella cooperi* Carpenter. U.S.N.M. 165273. Altitude 34 mm. Aperture view, $\times 2$. Waldorf asphalt mine (4473). Common in the Pliocene and Pleistocene.
- FIG. 12. *Drillia waldorfensis* Arnold. U.S.N.M. 165270. Type. Altitude 18.5 mm. Aperture view of imperfect specimen, $\times 2$. Waldorf asphalt mine (4473).





FERNANDO (PLIOCENE) GASTEROPODA.

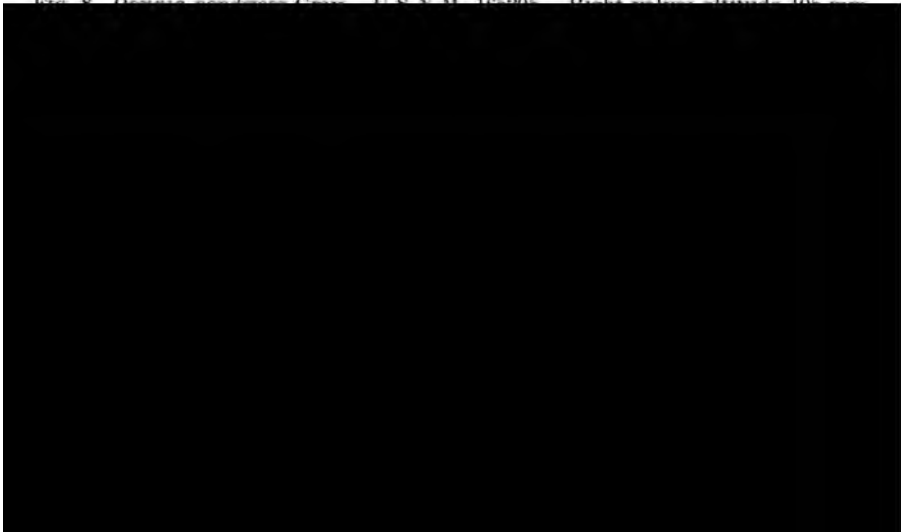
PLATE XXII.

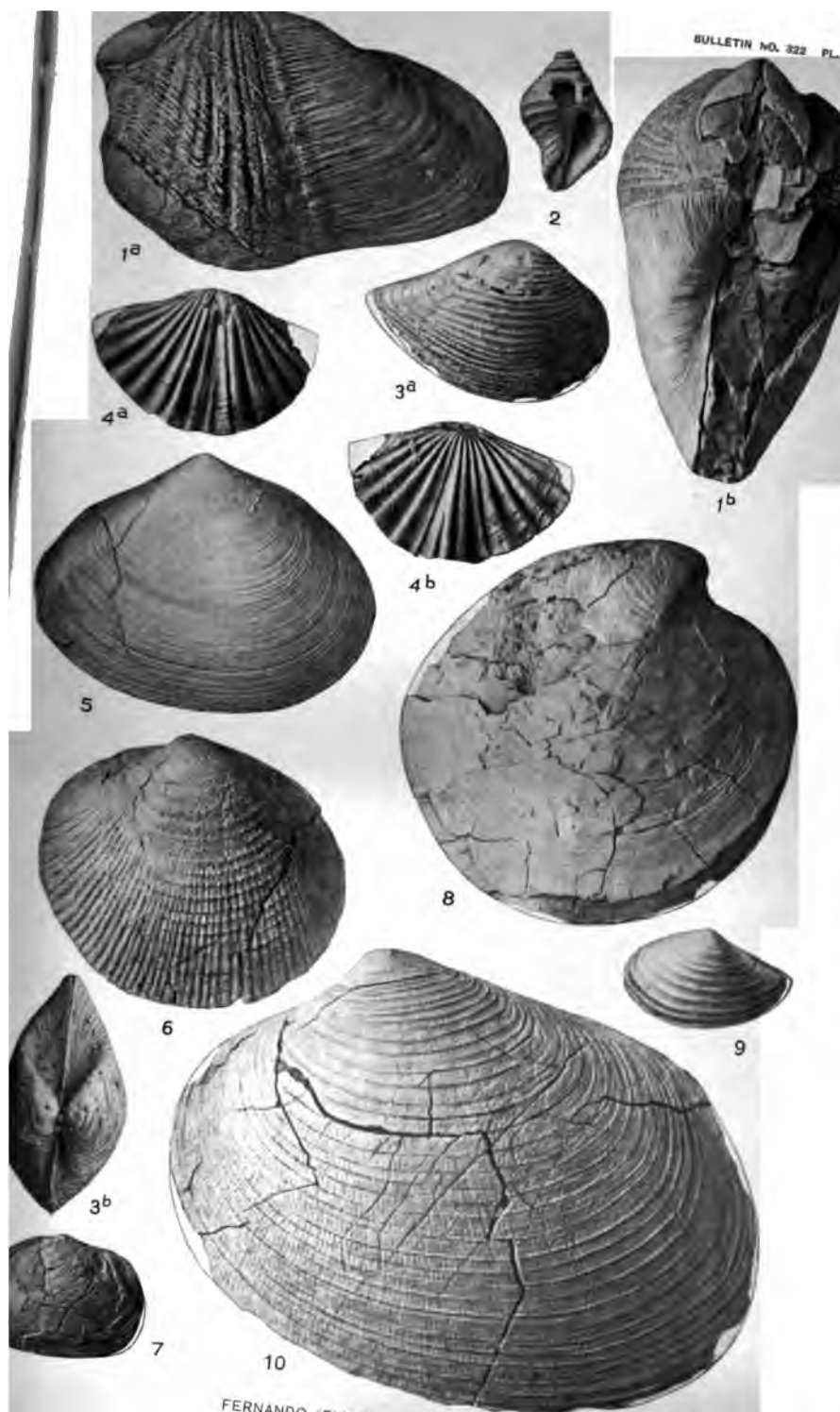
FERNANDO (PLIOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

- FIG. 1a. *Pholadidea ovoidea* Gould. U.S.N.M. 165277. Longitude 58 mm. View of valve. Waldorf asphalt mine (4473). Also known recent.
- FIG. 1b. View of hinge region of both valves.
- FIG. 2. *Purpura crispata* Chemintz. U.S.N.M. 165278. Altitude 20 mm. Aperture view. One mile north of Schumann (4474). Also known recent.
- FIG. 3a. *Leda taphria* Dall. U.S.N.M. 165296. Longitude 10.5 mm. View of exterior, $\times 3$. Fugler Point asphalt mine, near Gary (4475). Also known recent.
- FIG. 3b. View of hinge region of both valves.
- FIG. 4a. *Terebratalia occidentalis* Dall. U.S.N.M. 165300. Ventral valve; latitude 30 mm. View of exterior. Fugler Point asphalt mine, near Gary (4475). A variable species. Also known recent.
- FIG. 4b. View of dorsal valve of same specimen.
- FIG. 5. *Macoma nasuta* Conrad. U.S.N.M. 165276. Longitude 47 mm. View of right valve. Waldorf asphalt mine (4473). Also known recent and in Miocene.
- FIG. 6. *Phacoides nuttalli* Conrad var. *antecedens* Arnold. U.S.N.M. 165290. Type. Left valve; longitude 23 mm. View of exterior, $\times 2$. Alcatraz asphalt mine, near Siquoc (4471). Characteristic of this horizon.
- FIG. 7. *Cryptomya ovalis* Conrad. U.S.N.M. 165289. Left valve; longitude 23 mm. Alcatraz asphalt mine, near Siquoc (4471). Characteristic of this horizon.

FIG. 8. *Dactyloscapha* sp. U.S.N.M. 165295. Right valve; latitude 10.5 mm.





FERNANDO (PLIOCENE) FOSSILS.

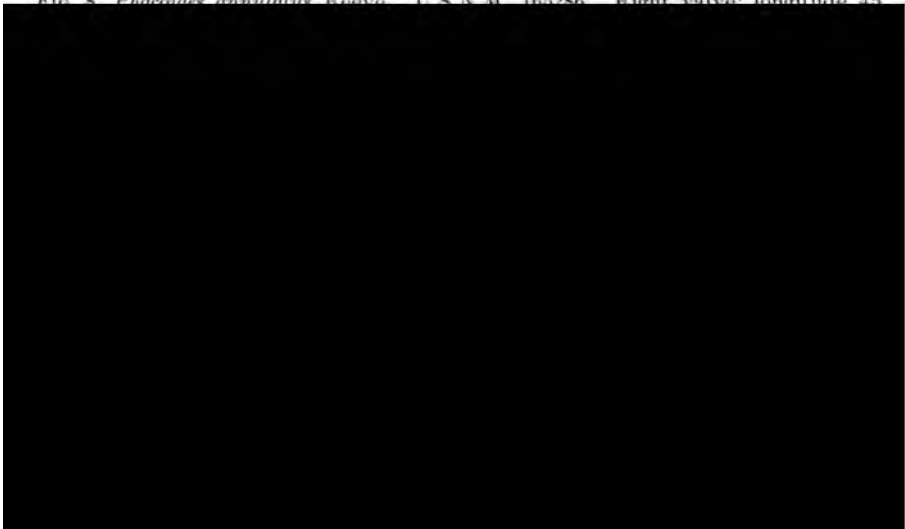
PLATE XXIII.

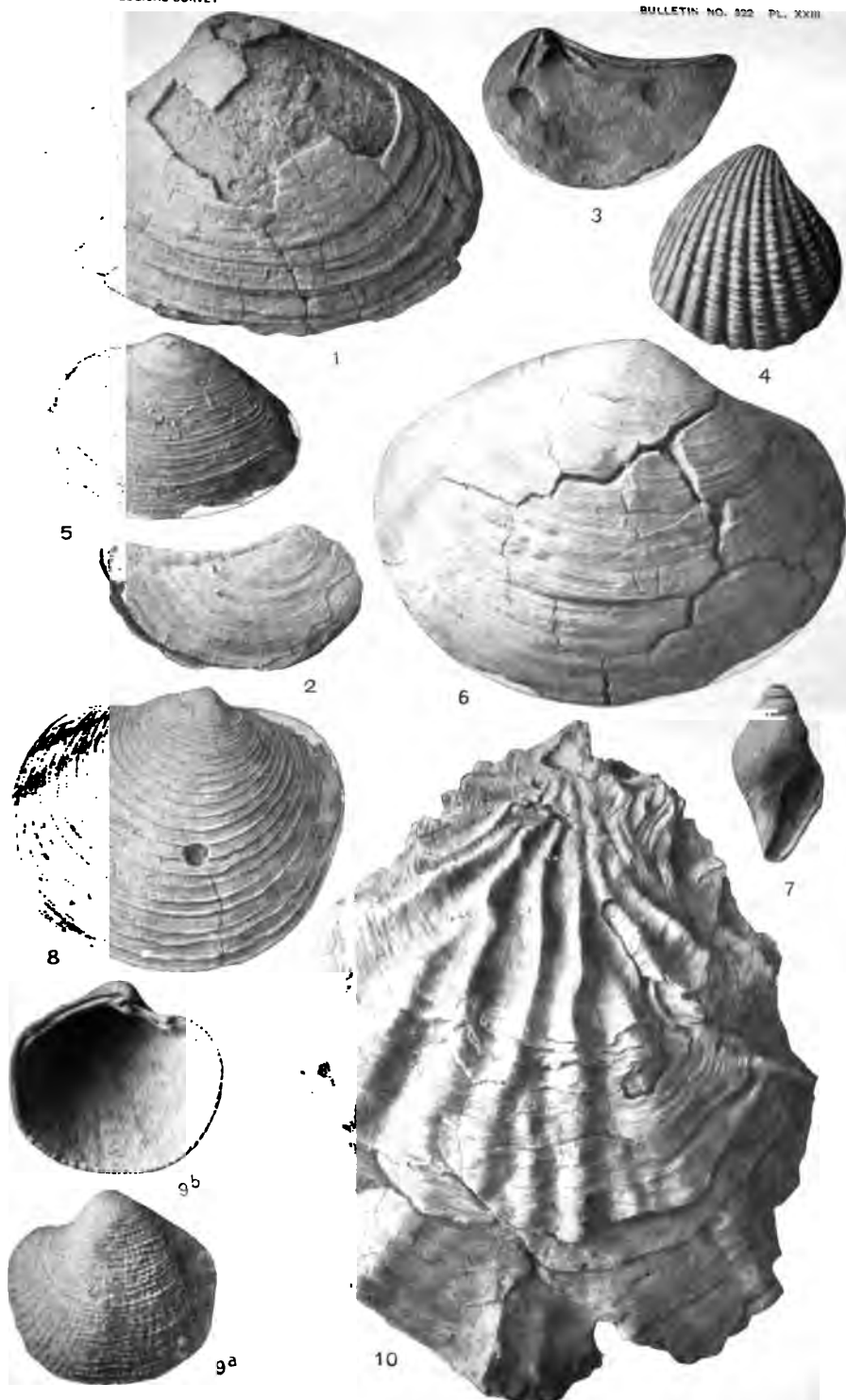
FERNANDO (PLIOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

- FIG. 1. *Spisula sisquocensis* Arnold. U.S.N.M. 165292. Type. Left valve; longitude 120 mm. View of exterior, $\times \frac{1}{2}$. Alcatraz asphalt mine, near Sisquoc (4471). Characteristic of this horizon.
- FIG. 2. *Clidiophora punctata* Carpenter. U.S.N.M. 165302. Right valve; longitude 36 mm. View of exterior. Graciosa Ridge, near Orcutt (4476). Also known recent.
- FIG. 3. *Clidiophora punctata* Carpenter. U.S.N.M. 165283. Left valve; longitude 35 mm. View of interior. Graciosa Ridge, near Orcutt (4476). Also known recent.
- FIG. 4. *Venericardia californica* Dall. U.S.N.M. 165274. Altitude 29 mm. Aperture view. Waldorf asphalt mine (4473). Characteristic of this horizon.
- FIG. 5. *Cumingia californica* Conrad. U.S.N.M. 165311. Left valve; longitude 17 mm. View of exterior, $\times 2$. Fugler Point asphalt mine, near Gary (4475). Also known recent.
- FIG. 6. *Spisula catilliformis* Conrad var. *alcatrazensis* Arnold. U.S.N.M. 165291. Type. Right valve; longitude 128 mm. View of exterior, $\times \frac{1}{2}$. Alcatraz asphalt mine, near Sisquoc (4471). Characteristic of this horizon.
- FIG. 7. *Bathytoma carpenteriana* Gabb var. *fernandoana* Arnold. U.S.N.M. 165303. Type. Altitude 24 mm. Aperture view. Graciosa Ridge, near Orcutt (4476). Characteristic of this horizon.

FIG. 8. *Phacoides annulatus* Reeve. U.S.N.M. 165286. Right valve; longitude 45





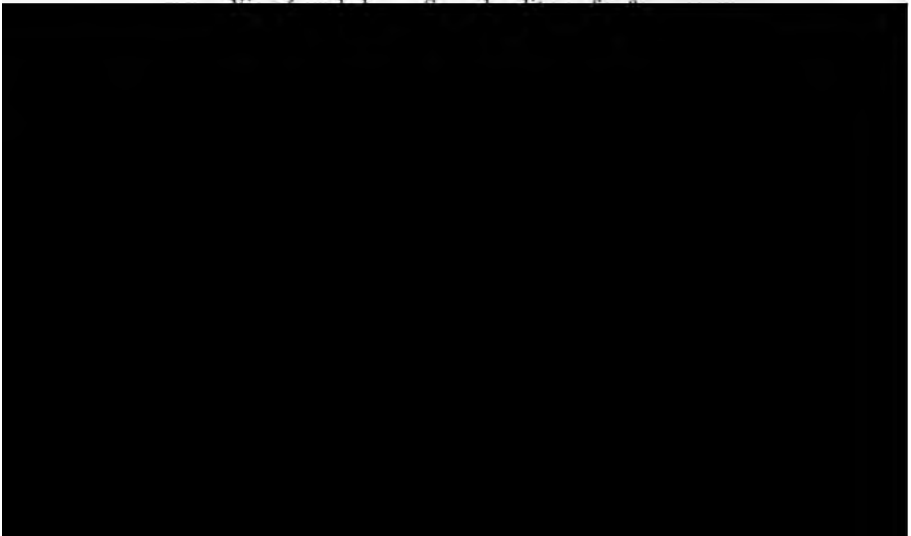
FERNANDO (PLIOCENE) FOSSILS.

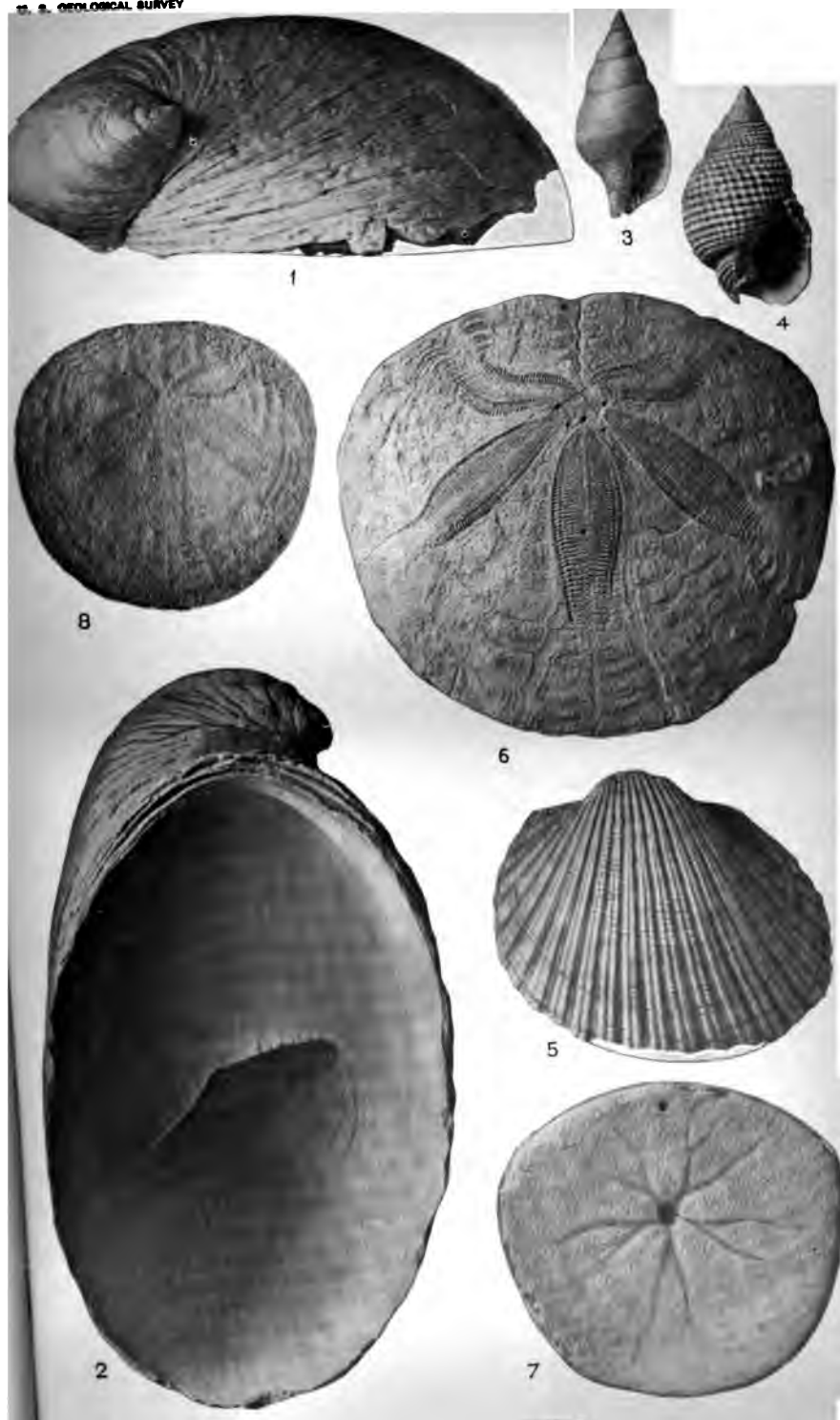
PLATE XXIV.

FERNANDO (PLIOCENE) FOSSILS.

(Unless otherwise indicated all figures are natural size.)

- FIG. 1. *Crepidula princeps* Conrad. U.S.N.M. 165268. Longitude 76 mm. Side view. Waldorf asphalt mine (4473). Known only in the fossil state, and found in Santa Barbara County only in the Fernando formation, although it is known from the lower Miocene farther north.
- FIG. 2. *Crepidula princeps* Conrad. U.S.N.M. 165315. Longitude 106 mm. View of interior, showing deck. Packards Hill, Santa Barbara.
- FIG. 3. *Astyris richthofeni* Gabb. U.S.N.M. 165266. Altitude 14 mm. Aperture view, $\times 2$. Waldorf asphalt mine (4473). So far known only as fossil.
- FIG. 4. *Nassa californiana* Conrad. U.S.N.M. 165304. Altitude 30 mm. Aperture view. Graciosa Ridge, near Orcutt (4477). Characteristic of this horizon in the Santa Maria district.
- FIG. 5. *Arca trilineata* Conrad. U.S.N.M. 165301. Left valve; longitude 46 mm. View of exterior. Fugler Point asphalt mine, near Gary (4475). Common in the Fernando and equivalent formations and also found in the Monterey.
- FIG. 6. *Echinarachnius ashleyi* Merriam. U.S.N.M. 165259. Maximum diameter 69 mm. View from above. Graciosa Ridge, near Orcutt (4469).
- FIG. 7. *Echinarachnius ashleyi* Merriam. U.S.N.M. 165259. Maximum diameter 47





FERNANDO (PLIOCENE) FOSSILS.

PLATE XXV.

FERNANDO (PLIOCENE) PECTENS.

(Unless otherwise indicated all figures are two-thirds natural size.)

FIG. 1a. *Pecten* (*Pecten*) *stearnsii* Dall. U.S.N.M. 148008. Right valve; altitude 87 mm. View of exterior. San Diego formation (Pliocene), Pacific Beach, San Diego County, Cal. Common in the Fernando formation of southern California.

FIG. 1b. Same specimen as fig. 1a. Exterior of left valve.

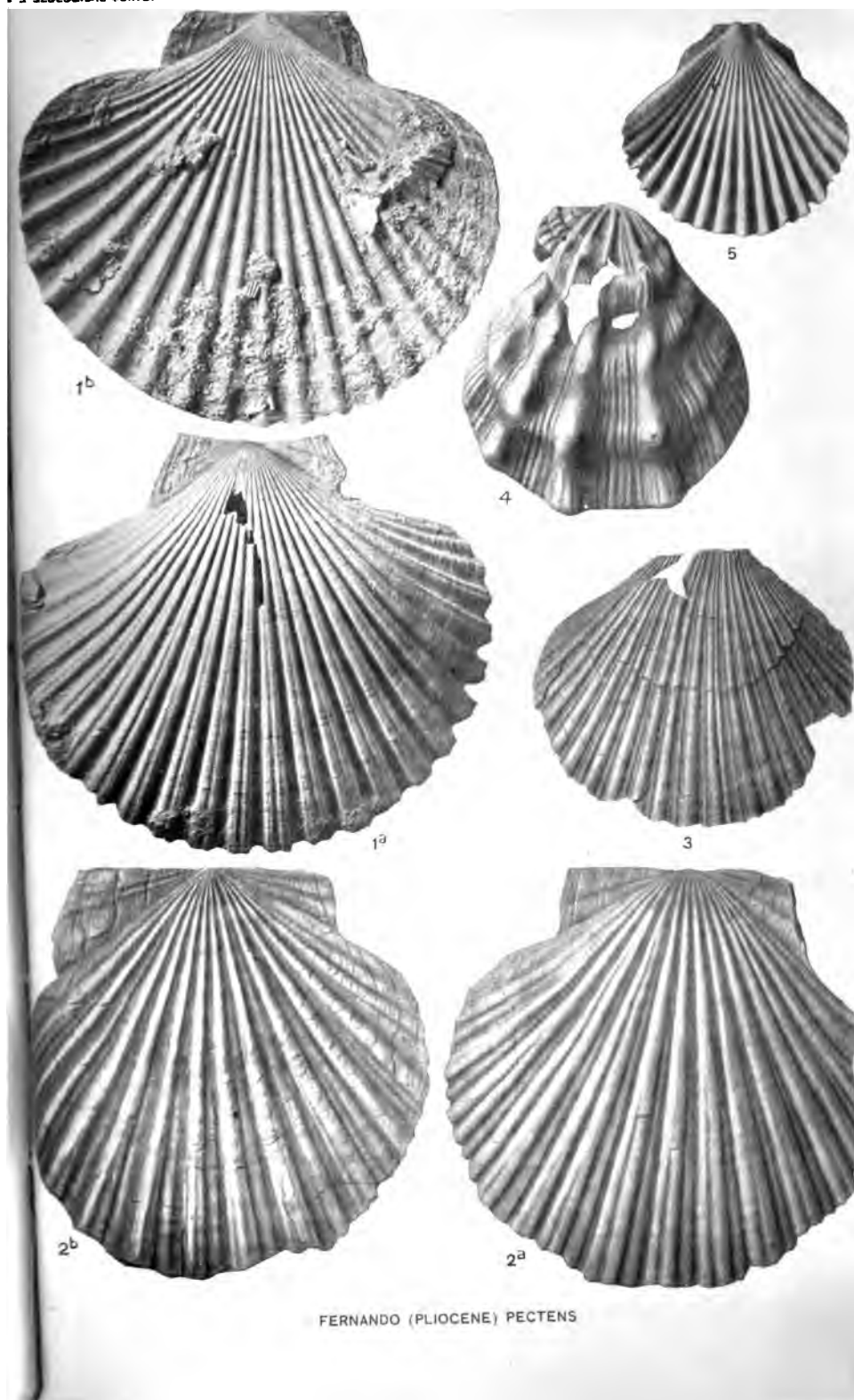
FIG. 2a. *Pecten* (*Patinopecten*) *oweni* Arnold. Collection of University of California. Type. Right valve, anterior ear slightly broken; altitude 85 mm. View of exterior. Foxen's ranch. Characteristic of this horizon.

FIG. 2b. Same specimen as fig. 2a. Exterior of left valve.

FIG. 3. *Pecten* (*Chlamys*) *lawsoni* Arnold. Collection of California Academy of Science. Type. Right valve (umbo and ears missing); longitude 65 mm. View of exterior. One mile north of Schumann. Characteristic of this horizon.

FIG. 4. *Pecten* (*Chlamys*) *wattsii* Arnold. Collection of California Academy of Science. Type. Slightly imperfect left valve; altitude 66 mm. View of exterior. Lower Pliocene. Kreyenhagen's ranch, Fresno County. Common





FERNANDO (PLIOCENE) PECTENS

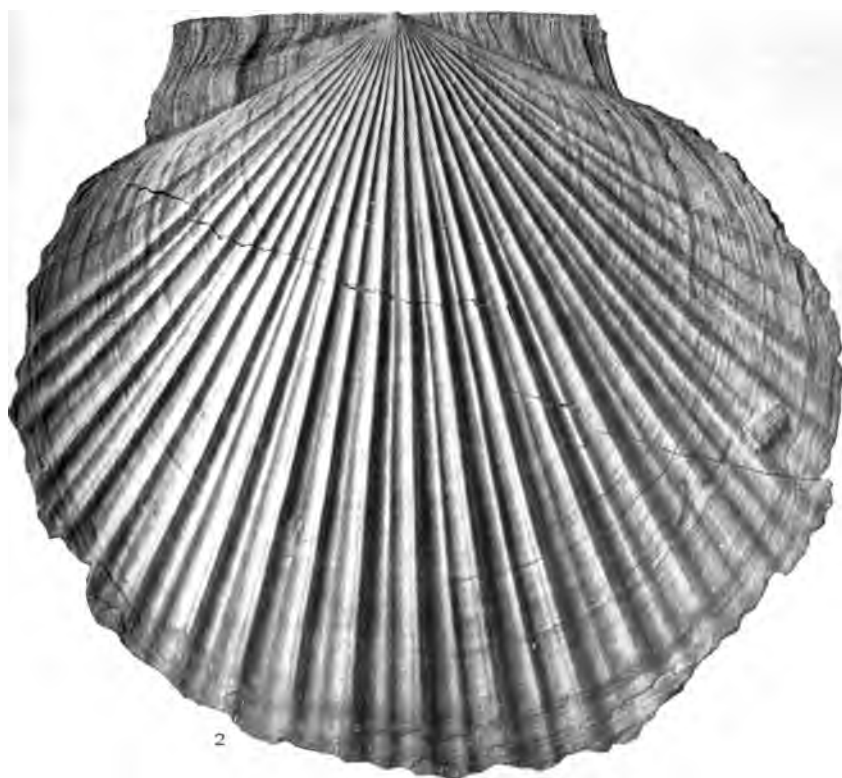
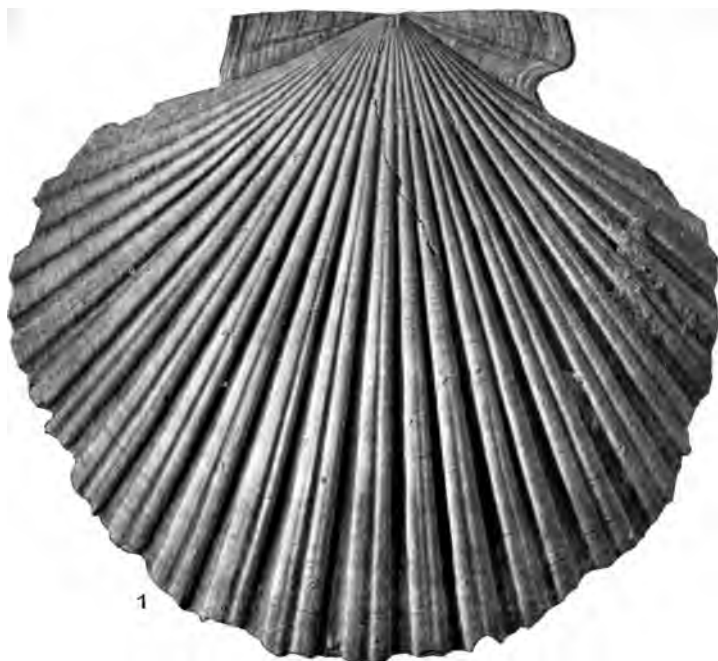
PLATE XXVI.

FERNANDO (PLIOCENE) PECTEN.

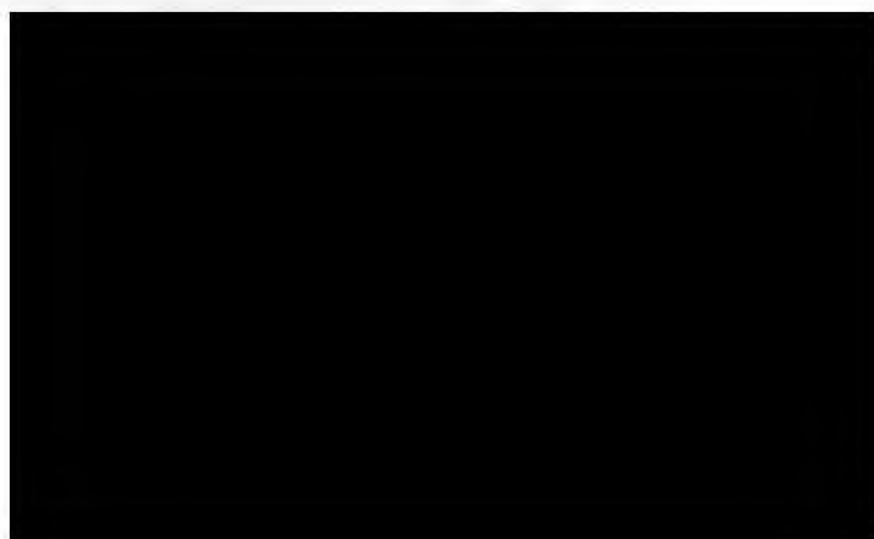
(Unless otherwise indicated all figures are two-thirds natural size.)

FIG. 1. *Pecten (Patinopecten) healeyi* Arnold. U.S.N.M. 148012. Holotype. Right valve; altitude 121 mm. View of exterior. San Diego formation (Pliocene), San Diego County, Cal. Characteristic of the Fernando formation throughout the Coast Range.

FIG. 2. *Pecten (Patinopecten) healeyi* Arnold. U.S.N.M. 154162. Paratype. Left valve; altitude 141 mm. View of exterior. San Diego formation (Pliocene), Pacific Beach, San Diego County, Cal.



FERNANDO (PLIOCENE) PECTENS



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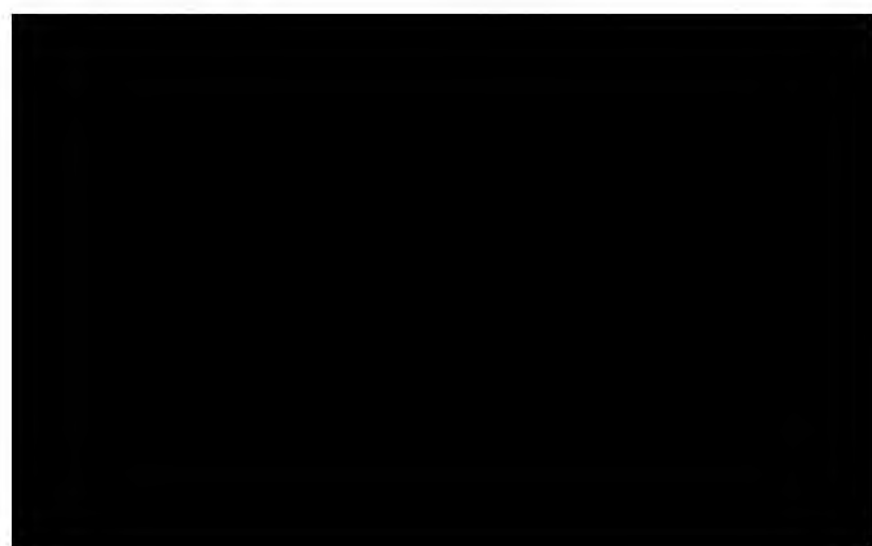
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[Bulletin No. 322.]

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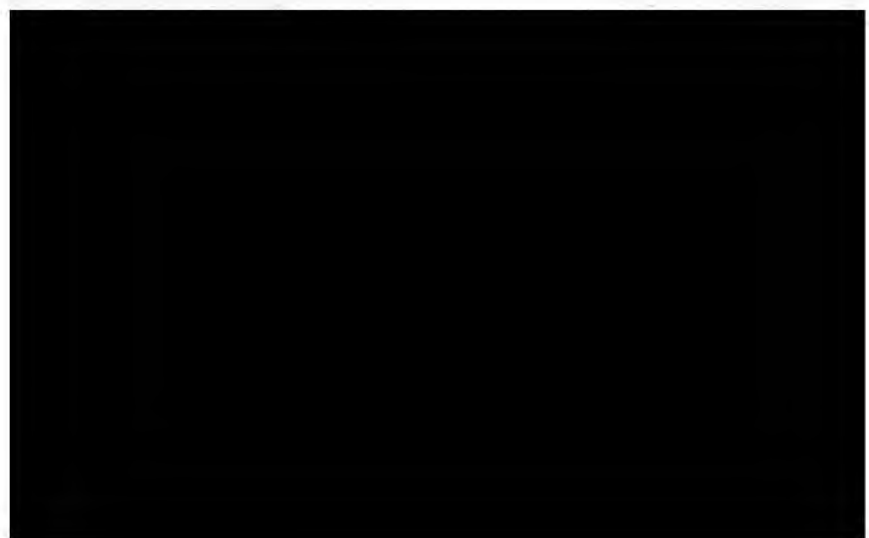
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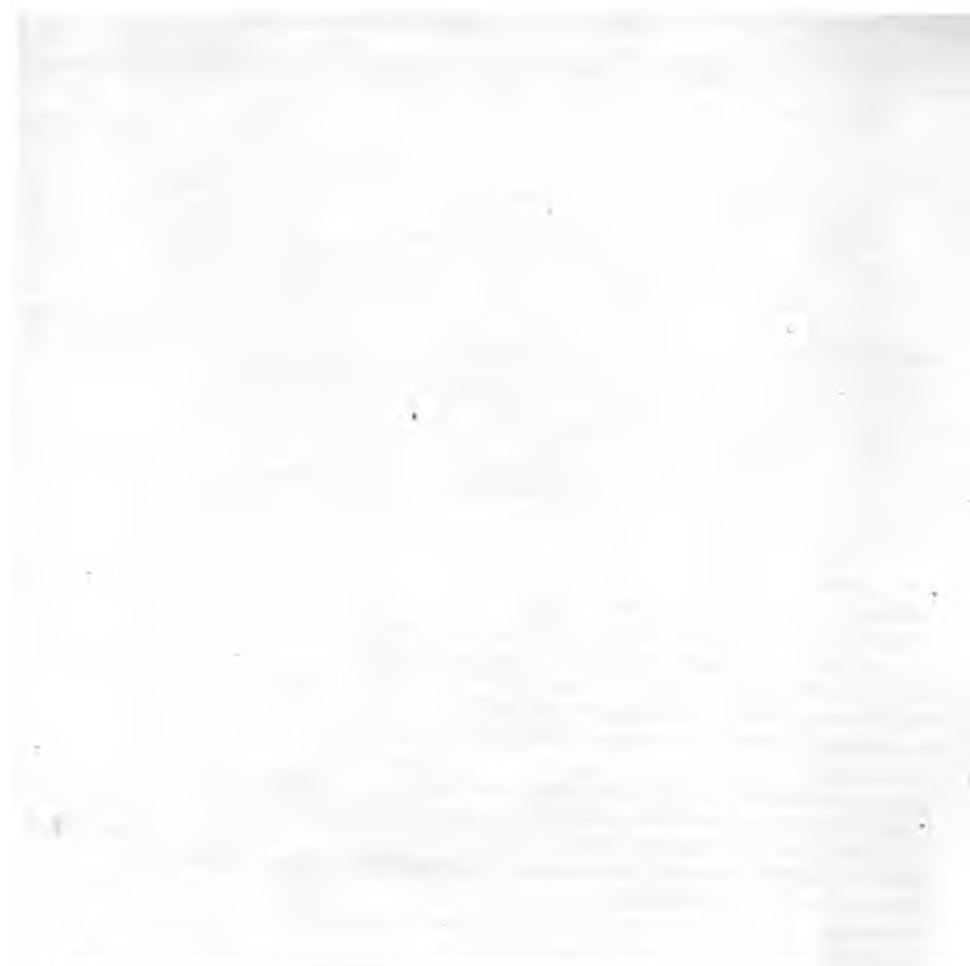




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EXPERIMENTAL WORK CONDUCTED IN THE CHEMICAL LABORATORY OF THE UNITED STATES FUEL-TESTING PLANT, ST. LOUIS, JANUARY 1, 1905, TO JULY 31, 1906.

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INTRODUCTION.

The experimental work reported upon herein was performed at the laboratory of the United States fuel-testing plant on the grounds of the Louisiana Purchase Exposition at St. Louis, Mo., between January 1, 1905, and July 31, 1906, and was undertaken for the purpose of checking the results obtained in the routine work of the laboratory, improving the methods of working, and investigating the chemical and physical properties of coal. The laboratory having been designed primarily for the analysis of the coal samples sent to the fuel-testing plant, as well as those taken in connection with the regular testing operations of the boiler, gas-producer, and other divisions of the plant, only a very small proportion of the time of the force was available for experimental work outside of the regular routine.

From the nature of such work it was not possible to separate the results obtained in 1905 from those obtained in 1906, especially as many of the experiments, such as those on the alteration of coal, involved a long time and were started in 1905 and continued to the middle of 1906. This report therefore covers all such work up to its completion in July, 1906.

The complete history of the coals used in these experiments is not given, the samples being usually referred to by their laboratory numbers only, as such information is generally not necessary and does not affect the interpretation of the results obtained in the experiments. Fuller information as to any particular sample may be found in the published reports of the fuel-testing plant for 1905 and 1906.

In the following pages the results of each line of experimental work are given under a special heading indicating the object of the investigation.

While many of the investigations can only be regarded as preliminary, it is believed that the mass of the results will be of value in shedding light on some matters of general interest.

ACCURACY OF METHOD OF TAKING CAR SAMPLES.

The regular method of taking car samples has been fully described under "Sampling" in Professional Paper No. 48, page 175. To check the accuracy of this method, check samples on two cars of coal rather high in moisture, ash, and sulphur were taken at the same time that the regular sample was taken, by opening a gate in the conveyor runway every four or five minutes, and thereby allowing the contents of one or two buckets passing at that time to be emptied into a small bin. In this way a sample of 1,200 to 1,500 pounds was taken during the unloading of the car. This sample was then put through a small crusher, crushed to $\frac{1}{2}$ -inch size, and resampled at the conveyor buckets, and a sample was sent to the chemical laboratory for analysis. In the following table the Indiana coal was a run-of-mine coal, and the amount sampled was approximately 20 tons; and the Ohio coal was a run-of-mine coal, and the amount sampled was approximately 26 tons.

Moisture, ash, and sulphur determinations from samples of two cars of run-of-mine coal.

Constituent.	Indiana coal.		Ohio coal.	
	Regular sample.	Check sample.	Regular sample.	Check sample.
Moisture	10.80	10.47	9.01	9.43
Ash	12.62	12.92	11.33	11.59

analysis of this sample, and analysis of the portion of the sample reduced at once, are as follows:

	Per cent.
Portion sampled at once	5.07
Portion sampled after standing five days	4.58
Loss by standing	.49

These coals dry down to about 1 per cent moisture, so that the loosely held and surface moisture amounted to about 4 per cent. From this experiment the moisture loss which occurs during the short time that the sample usually is allowed to stand in the laboratory before sampling would appear to be unimportant.

INVESTIGATION OF MOISTURE LOSSES DURING SAMPLING.

In preparing the samples for these tests the coarse sample (40 to 50 pounds in weight), when received at the laboratory, was divided by quartering. One portion of 500 grams was at once ground without air drying in the ball mill. Another portion of about 5 to 10 pounds was air dried in the usual way before the final pulverization. The results (reduced to sample as received) in moisture and ash for the two portions are as follows:

Moisture and ash determinations on air-dried samples and fresh samples of coal.

Designation of sample.	Regular sample (air dried).		Fresh sample (not air dried).	
	Moisture.	Ash.	Moisture.	Ash.
Illinois.....	13.54	10.74	9.36	11.37
Texas No. 4.....	13.72	10.32	11.92	10.40
Arkansas No. 8.....	33.85	7.30	33.00	7.65
Indiana No. 12.....	5.19	14.01	3.58	14.16
Illinois No. 23.....	10.57	11.65	9.95	11.98
Illinois No. 23 B.....	15.68	15.59	14.78	16.11
Illinois No. 23 A.....	13.47	11.53	12.43	11.63
Missouri No. 6.....	13.80	11.74	12.58	11.15
Illinois No. 22 A.....	11.91	13.01	11.58	12.57

^aThis sample was ground very fine in ball mill, which probably accounts for the loss being so large.

The results obtained for moisture from the original samples that were ground down without preliminary air drying are without exception decidedly lower than the results obtained from the regularly prepared air-dried samples when calculated to the sample as received, the greatest difference being over 4 per cent and the average difference over 1½ per cent. Furthermore, the fine sample, after being ground without previous air drying, as shown by experiments (see pp. 13-17), gives up moisture so readily as to indicate that a large additional loss during the handling and weighing of the sample in the laboratory is almost certain. The consequent errors due to moisture losses are liable to be so large as to affect very seriously the accuracy of the results obtained.

DETERMINATION OF ERRORS DUE TO ABRASION OF PEBBLES USED IN BALL MILL.

During the Louisiana Purchase Exposition the final pulverization of the samples was done on a bucking board. In the work done during 1905 the final grinding of the sample was done in closed jars in the ball mill, quartz pebbles being used.

In order to determine whether there was danger of materially increasing the ash contents of the samples from chipping and abrasion of the pebbles used in grinding, these pebbles were carefully weighed at intervals and the amount of loss determined. The weight of the sample ground each time in the ball mill is approximately 500 grams, and the abrasion of the pebbles (calculated as percentage of the weight of the samples ground) was also carefully determined. The results on three weighed lots of pebbles are as follows:

Losses of weight in three lots of quartz pebbles before and after grinding in the ball mill.

Lot.	Total weight of samples ground.	Weight of pebbles.		Loss by abrasion.	
		Before grinding.	After grinding.	Actual.	Ratio to coal ground.
	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Per cent.</i>
No. 1 (250 samples ground).....	125,000	1,118.6	4,113.1	5.5	0.004
No. 2 (230 samples ground).....	115,000	3,502.9	3,499.4	3.5	.003
No. 3 (245 samples ground).....	122,500	4,273.2	4,268.3	4.9	.004

These results show that as far as the fine pulverization of the coal is concerned, there is little or no danger of increasing the ash content

to time and the drying continued until the weight remained almost constant. The air-drying loss of these samples and the loss in weight of the corresponding regular samples dried in the dryer, with the amount of moisture remaining in the dryer samples, are tabulated below. In most of the samples the dryer loss is not widely different from the loss on the air-dry sample. Special exceptions are Nos. 1960 (Indiana No. 9 B) and 1390 (Wyoming No. 6), on which samples the dryer-sample loss is decidedly larger than that on the samples dried by exposure to the air of the laboratory. The samples dried during the summer months were exposed to air of a high average humidity (60 per cent), as the temperature and humidity of the laboratory were approximately that of the outdoor air for that period. The samples dried during the winter months were exposed to air of low average humidity (30 per cent), as the temperature of the laboratory was decidedly higher than that of the outdoor air, with approximately the same absolute amount of moisture present in the laboratory and in the outdoor air. The humidity of the warmer laboratory air is consequently low. The percentage of moisture remaining in the samples dried by exposure to the air of the laboratory was determined by adding or subtracting (according to whether it was plus or minus) the difference between the loss in the dryer and the loss in the exposed sample to the moisture remaining in the "dryer sample," as given in the table below:

Results of tests for moisture in samples of coal.

Sample of coal.			Moisture in sample.				Air of laboratory.		
Laboratory number.	Field number.	As received	Loss on coarse sample, as dried—		After drying—		Time of drying by exposure	Temperature.	Humidity.
			By exposure.	In dryer.	By exposure (calculated).	In dryer.			
		Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Days.	° C.	Per ct.
3294	New Mexico No. 5.....	2.72	1.60	1.40	1.14	1.34	17	25	63
3265	Alabama No. 3.....	2.72	0.30	1.20	2.44	1.54	13	25	64
3308	New Mexico No. 3.....	2.75	1.40	1.40	1.37	1.37	19	25	63
3331	New Mexico No. 4 A.....	2.78	0.40	1.40	2.40	1.40	14	24	62
3406	Indian Territory No. 2 B.....	2.81	0.60	1.40	2.23	1.43	16	26	64
2628	West Virginia No. 20.....	2.89	1.98	1.90	0.93	1.01	16	21	26
3315	New Mexico No. 4 B.....	3.38	1.60	1.70	1.81	1.71	18	25	62
3295	New Mexico No. 3 A.....	3.45	1.50	2.00	1.98	1.48	17	25	63
2352	West Virginia No. 17.....	3.46	2.07	2.50	1.43	1.00	11	21	47
2572	West Virginia No. 21.....	3.57	2.24	2.10	1.36	1.50	12	19	28
2420	Virginia No. 1.....	4.06	2.59	2.40	1.51	1.70	9	25	27
3307	New Mexico No. 3 B.....	4.36	2.20	3.00	2.20	1.40	19	25	63
2528	Kentucky No. 5.....	4.36	1.77	2.80	2.63	1.60	10	24	31
2264	West Virginia No. 16 B.....	5.57	3.89	4.40	1.73	1.22	11	18	57
3286	Utah No. 1.....	5.83	2.30	2.10	3.61	3.81	17	25	63
3405	Indian Territory No. 2 B.....	6.27	4.20	4.90	2.14	1.41	16	26	64
1761	Illinois No. 15.....	9.95	3.62	1.20	6.58	6.00	18	27	64
1876	Indiana No. 6.....	10.47	6.02	6.30	4.73	4.45	14	27	64
3225	Wyoming No. 5.....	11.44	4.10	3.70	7.64	8.01	21	25	53
2696	Illinois No. 22 B.....	13.03	9.74	11.20	3.52	2.06	8	23	35
1960	Indiana No. 9 B.....	13.53	7.13	10.70	6.74	3.17	18	27	67
2686	Washington No. 1 B.....	14.30	8.12	9.60	6.68	5.20	9	22	34
2731	Illinois No. 20.....	14.68	11.80	12.40	3.20	2.60	11	23	34
2608	Illinois No. 23 B.....	15.68	13.98	13.20	2.08	2.86	10	24	31
3380	Wyoming No. 6.....	19.00	7.50	11.30	12.48	8.68	16	21	64

These values show that on most of the coals tested drying in the drier brought the sample to approximately an air-dry condition. No effort had been made to do more than this, as the primary object in the air drying is to get the sample into such a condition that the fine sample will not be subject to large moisture changes during subsequent handling in the laboratory. The air drying, therefore, is not to be understood as being a rigidly fixed determination; but it has been found that the values obtained as a rule are within a sufficiently definite range to give this determination some importance as showing the effect of standing and exposure on the percentage of moisture in the coal. This matter is of considerable commercial importance, since, so far as the moisture content is concerned, coals having a large air-drying loss are obviously much more affected than coals having a small air-drying loss. It further has appeared that the amount of residual moisture in the air-dried sample prepared under the described conditions usually lies within a range which is somewhat characteristic of different kinds of coal.

The foregoing table shows this residual moisture to be about 1 per cent in the West Virginia coals, 3 to 6 per cent in the Illinois and Indiana coals, and from 10 to 12 per cent in the Wyoming samples.

COMPARISON OF RESULTS FOR MOISTURE OBTAINED FROM SAMPLES PULVERIZED BY VARIOUS METHODS.

The possibility of moisture loss during grinding on a bucking board has already been referred to. In order to obtain more data upon different coals and under observed conditions of temperature and humidity, duplicate portions of a number of coals were ground



MOISTURE AS AFFECTED BY PULVERIZATION.

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Results for moisture from coal samples variously pulverized.

Laboratory number.	Sample of coal.	Moisture in sample from—			Air of laboratory.	
		Bucking board.	Ball mill.	$\frac{1}{16}$ -inch mesh sieve.	Temperature.	Humidity.
	Field number.	Per cent.	Per cent.	Per cent.	° C.	Per cent.
2255	Alabama No. 3.....	1.43	1.54	1.43	29	65
2689	Arkansas No. 1 B.....	0.89	0.85	0.69	23	30
2688	Arkansas No. 7 A, 7 B.....	0.62	0.60	0.50	23	30
2722	Arkansas No. 7 B.....	0.94	1.05	0.87	23	30
2744	Arkansas No. 8.....	0.75	0.83	0.81	28	37
2690	Arkansas No. 9.....	1.22	1.11	1.03	23	30
1835	Brazil.....	5.40	4.95	4.80	30	67
1680	California No. 1.....		9.05	7.28	29	60
1699	do.....		8.89	7.42	22	61
1702	Illinois No. 6 B.....		4.17	4.22	27	52
1780	Illinois No. 7 D.....	6.82	7.00	7.48	24	70
1635	Illinois No. 9 A.....	4.92	4.99	5.36	20	50
1639	Illinois No. 9 B.....		4.03	3.73	25	39
1638	do.....	10.58	12.34	12.35	21	60
1648	Illinois No. 10.....		2.79	2.94	28	37
1653	Illinois No. 11 A.....		2.98	2.59	24	56
1654	do.....		3.11	2.82	24	55
1717	Illinois No. 11 C.....	2.97	2.42	2.39	27	64
1802	Illinois No. 11 D.....	6.06	6.30	6.01	26	64
1786	Illinois No. 13.....	4.22	3.89	3.68	25	63
1740	Illinois No. 14.....	5.24	5.19	5.29	35	58
1761	Illinois No. 15.....	6.10	6.00	5.84	25	77
1820	Illinois No. 16.....	4.74	4.61	4.46	28	72
1926	Illinois No. 19 A.....	6.46	6.29	6.20	31	56
3447	Illinois No. 19 C.....	5.43	6.01	5.57	33	49
3448	Illinois No. 19 D.....	3.96	3.87	3.95	33	49
3451	do.....	4.83	5.27	4.95	33	49
2731	Illinois No. 20.....	2.89	2.60	2.67	25	39
2652	Illinois No. 21.....	4.42	5.74	5.61	23	30
2805	Illinois No. 22 A.....	4.45	6.39	6.39	24	30
2896	Illinois No. 22 B.....	2.14	2.06	1.85	24	31
2808	Illinois No. 23.....	2.47	2.86	2.65	24	31
2619	Illinois No. 23 A.....	2.05	2.28	1.93	22	28
1941	Indiana No. 3.....	5.19	5.12	4.98	29	60
1844	Indiana No. 4.....	4.04	3.58	3.42	28	72
1859	Indiana No. 5.....	5.62	5.21	5.60	21	68
1875	Indiana No. 6.....	5.76	5.91	5.71	21	60
1881	Indiana No. 7 A.....	5.60	5.50	5.46	27	71
2037	Indiana No. 8.....	3.99	5.19	5.16	23	69
1960	Indiana No. 9 B.....	3.30	3.17	3.04	28	72
1979	Indiana No. 10.....	2.94	2.85	2.62	31	63
2087	Indiana No. 11.....	7.92	8.49	8.52	22	75
2759	Indiana No. 12.....	3.45	4.45	4.29	19	35
3405	Indian Territory No. 2 B.....	1.70	1.44	1.34	31	63
3406	do.....	1.65	1.43	1.38	31	63
2943	Kansas No. 6.....	1.71	2.09	1.83	24	28
2528	Kentucky No. 5.....	1.68	1.60	1.34	13	37
2592	Kentucky No. 6.....	2.66	2.99	2.80	22	28
2274	Maryland No. 1.....	1.12	0.94	0.99	24	70
2865	Missouri No. 5.....	1.59	1.71	1.55	24	25
2904	Missouri No. 6.....	1.63	2.49	2.62	24	31
2837	Missouri No. 7.....	5.25	7.41	7.45	21	83
2942	do.....	2.54	2.48	2.28	20	37
3235	New Mexico No. 3.....	1.03	1.18	1.34	30	57
3307	New Mexico No. 3 B.....	1.43	1.40	1.38	28	65
3308	do.....	1.33	1.37	1.33	25	65
3315	New Mexico No. 4.....	1.56	1.71	1.64	28	43
3331	New Mexico No. 4 A.....	1.54	1.40	1.14	31	47
3294	New Mexico No. 5.....	1.36	1.34	1.24	30	67
2071	Ohio No. 1.....	3.40	2.96	2.65	21	72
2109	Ohio No. 2.....	5.60	5.60	5.57	27	72
2144	Ohio No. 3.....	5.43	6.24	6.15	14	73
2083	Ohio No. 4.....	2.56	2.16	1.91	21	85
2062	Ohio No. 5.....	2.25	1.99	1.84	18	73
2310	Ohio No. 9 A.....	2.35	2.47	2.56	19	66
2311	Ohio No. 9 B.....	2.78	2.65	2.37	19	66
2115	Pennsylvania No. 5 A.....	1.82	1.77	1.77	24	76
2068	Pennsylvania No. 5 B.....	1.57	1.47	1.38	21	75
2152	Pennsylvania No. 8.....	0.77	0.64	0.87	31	53
3102	Tennessee No. 6.....	1.27	1.02	1.02	20	38
3127	Tennessee No. 8 A.....	1.01	1.05	0.98	25	33
3128	Tennessee No. 8 B.....	0.92	1.14	1.02	25	33
2784	Texas No. 3.....	9.06	9.88	8.48	23	24
2717	Texas No. 4.....	8.63	9.76	8.67	21	26
3199	Utah No. 1.....	2.23	2.34	2.32	24	33
2420	Virginia No. 1 A.....	1.60	1.70	1.60	24	28

a Heated two hours, moisture = 7.86; heated three hours, moisture = 8.83.

Results for moisture from coal samples variously pulverized—Continued.

Sample of coal.		Moisture in sample from—			Air of laboratory.	
Laboratory number.	Field number.	Bucking board.	Ball mill.	$\frac{1}{8}$ -inch mesh sieve.	Temperature.	Humidity.
		Per cent.	Per cent.	Per cent.	° C.	Per cent.
2358	Virginia No. 4.....	2.35	2.40	2.28	28	26
2687	Washington No. 1 A.....	5.38	5.98	5.85	20	24
2686	Washington No. 1 B.....	4.55	5.20	4.65	20	24
2250	West Virginia No. 4 B.....	1.45	1.35	1.19	23	69
2028	West Virginia No. 13.....	1.10	1.17	1.15	23	69
2004	West Virginia No. 14.....	2.00	2.05	2.05	34	50
2332	West Virginia No. 17.....	1.15	1.00	1.00	20	59
2527	West Virginia No. 18.....	1.29	1.28	1.13	23	87
2549	West Virginia No. 19.....	0.65	0.68	0.65	22	22
2572	West Virginia No. 21.....	1.43	1.50	1.44	20	24
2131	Wyoming No. 2 B.....	4.57	4.65	4.48	23	85
3213	Wyoming No. 5.....	5.61	6.00	6.04	31	46
3390	Wyoming No. 6.....	8.90	8.68	8.24	32	55

The results for moisture obtained on the 5-gram portion of the coarse sample, as a rule, run from 0.1 to 0.2 per cent lower than the moisture value as determined upon the sample ground in the ball mill. In a few cases the moisture result on the coarse sample is somewhat higher than the result on the ball-mill sample, while in a few other cases, noticeably the lignite samples from California and Texas, the moisture result on the coarse sample is decidedly lower. This result, as shown by tests on sample 1680, California No. 1, may be ascribed to the fact that the moisture in a coarse sample of lignite is very incompletely expelled by one hour's heating. An additional two hours of heating upon this sample resulted in an increased moisture value of over 0.7 per cent. As a method applied to any and all coals, the determination of the moisture in the fine sample appears to be prefer-

following heading, showing the rapid changes in moisture in coal samples when spread on the watch glass, indicate that there is probably a slight gain or loss of moisture in the ball-mill sample even during the short time that this sample is exposed to air during sampling, and that this change may be considerable if the coarse sample be very far from an air-dried condition before being ground down. The grinding down of samples in the ball mill can not, therefore, be considered as perfectly satisfactory in so far as moisture changes are concerned; but this method of grinding, in connection with the preliminary drying of the coarse sample, is much more satisfactory and reliable than any other practical method that has been devised of which the writer has any knowledge. Therefore it appears that the handling of samples in this manner, as compared with the practice in most general use, is an important step in the direction of securing a sample for analysis with a minimum amount of unaccounted-for changes in moisture.

CHANGES IN MOISTURE CONTENT OF FINE SAMPLES OF COAL UNDER MODIFIED CONDITIONS.

That coal in a fine condition changes rapidly in moisture content is well known. In order to obtain definite information as to the rate of this change a number of tests were made on coals under different conditions. The first selection for testing was a fine sample (No. 1638 C) of undried Illinois coal, containing 12.4 per cent moisture. One gram of this sample was spread out on a 4-inch watch glass and weighed at intervals, a record of the temperature and humidity being taken at the time of the different weighings. A second series of tests was also made on a 10-gram portion of this sample spread upon a 4-inch watch glass. A third series of tests was made upon another portion of this sample (17.2 grams) by allowing it to stand in an open, wide-mouthed 2-ounce bottle and weighing at intervals. The results for these three series of tests are as follows:

Changes in moisture content of sample (No. 1638 C) of undried Illinois coal.

FIRST SERIES—1 GRAM ON 4-INCH WATCH GLASS.

Time interval between weighings.	Loss or gain in weight.	Air of laboratory.	
		Temperature.	Humidity.
	Grams.	° C.	Per cent.
5 minutes.....	-0.0202	22	21
5 minutes.....	-.0075		
15 minutes.....	-.0090		
1½ hours.....	-.0110	25	50
24 hours.....	-.0350	24	36
24 hours.....	-.0120	28	36
25 hours.....	+ .0140	25	63
42 hours.....	+ .0060	18	64
104 hours.....	-.0127	27	35
15 days.....	+ .0007	32	41
48 days.....	- .0176	32	36
Total loss in 72 days.....		10.42	

Changes in moisture content of sample (No. 1638 C) of undried Illinois coal—Continued.

SECOND SERIES—10 GRAMS ON 4-INCH WATCH GLASS.

Time interval between weighings.	Loss or gain in weight.	Air of laboratory.		
		Temperature.	Humidity.	
	Grams.	Per cent.	° C.	Per cent.
5 minutes.....	0.0280	-0.28	25	50
5 minutes.....	.0380	.38		
15 minutes.....	.0605	.61		
1½ hours.....	.1965	1.96	25	43
21 hours.....	.2535	2.54	24	36
24 hours.....	.2140	2.14	28	35
25 hours.....	+ .0575	+.58	25	63
42 hours.....	.0130	+.13	18	64
104 hours.....	.0518	.52	27	65
15 days.....	.0622	.62	32	41
48 days.....	.0725	.72	32	55
Total loss in 72 days.....		9.06		

THIRD SERIES—17.2 GRAMS IN OPEN, WIDE-MOUTHED 2-OUNCE BOTTLE.

10 minutes.....	- 0.0025	- 0.014	22	61
1½ hours.....	.0115	.067		
3½ hours.....	.0260	.15		
21 hours.....	.0800	.47	24	36
Stirred and reweighed.....	.0020	.01		
24 hours.....	.0855	.50	28	36
Stirred with spoon.....	.0020	.01		
26 hours.....	.0885	.51	25	63
Stirred with spoon.....	.0015	.01		
42 hours.....	.0625	.36	18	64
Stirred with spoon.....	.0010	.005		
4 days.....	.1190	.70	27	35
Stirred with spoon.....	.0005	.003		
15 days.....	.2625	2.11	32	41
Stirred with spoon.....	.0000	.000		
48 days.....	.0200	.116	32	55
Total loss in 72 days.....		5.035		

A second sample (No. 1638 E) of undried Illinois coal contained 11.89

CHANGES IN MOISTURE CONTENT.

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Changes in moisture content of sample (No. 1638 E) of undried Illinois coal—Continued.

SECOND SERIES—10 GRAMS ON 3-INCH WATCH GLASS.

Time interval between weighings.	Loss or gain in weight.		Air of laboratory.	
			Temperature.	Humidity.
	Grams.	Per cent.	° C.	Per cent.
5 minutes.....	-0.0518	-0.52	25	50
5 minutes.....	-0.0270	-0.27		
15 minutes.....	-0.0530	-0.53		
1 1/2 hours.....	-2.180	-2.18	25	43
2 1/2 hours.....	-2.000	-2.00	24	36
2 1/2 hours.....	-1.937	-1.94	28	36
25 hours.....	-0.0692	-0.69	25	38
42 hours.....	-0.0985	-0.985	18	64
104 hours.....	-0.0550	-0.55	27	35
15 days.....	-0.0590	-0.59	32	41
48 days.....	-0.0870	-0.87	32	55
Total loss in 72 days.....		8.67		

THIRD SERIES—14.5 GRAMS IN OPEN, WIDE-MOUTHED 2-OUNCE BOTTLE.

10 minutes.....	-0.003	-0.02	22	61
1 1/2 hours.....	-0.0135	-0.09		
3 1/2 hours.....	-0.0310	-0.23		
2 1/2 hours.....	-0.0890	-0.60	24	36
Stirred with spoon.....	-0.0020	-0.01		
24 hours.....	-0.0995	-0.68	25	36
Stirred with spoon.....	-0.0025	-0.02		
25 hours.....	-0.0850	-0.56	25	63
Stirred with spoon.....	-0.0015	-0.01		
42 hours.....	-0.0825	-0.42	18	64
Stirred with spoon.....	-0.0010	-0.01		
104 hours.....	-0.0875	-0.60	27	55
Stirred with spoon.....	-0.0015	-0.01		
15 days.....	-1.2538	-1.71	32	41
Stirred with spoon.....	-0.0010	-0.01		
48 days.....	-0.0500	-0.35	32	55
Total loss in 72 days.....		5.33		

Other experiments were likewise performed on a similar sample (No. 1639 C) of Illinois coal, which contained 4.12 per cent moisture, although the coarse sample had been well air-dried before the preparation of the fine sample. The changes in weight in the 1-gram sample spread on a watch glass, in the 10-gram sample spread on a watch glass, and in a portion (8.3 grams) allowed to stand exposed in an open, wide-mouthed 2-ounce bottle were as follows:

Changes in moisture content of sample (No. 1639 C) of well-dried Illinois coal.

FIRST SERIES—1 GRAM ON 4-INCH WATCH GLASS.

Time interval between weighings.	Loss or gain in weight.	Air of laboratory.		
		Temperature.	Humidity.	
	Grams.	Per cent.	° C.	Per cent.
5 minutes.....	-0.0093	-0.93	28	36
5 minutes.....	.0025	.25		
15 minutes.....	-.0015	-.15		
2 1/2 hours.....	+ .0045	+ .45		
23 hours.....	+ .0135	+1.35	25	63
2 days.....	+ .0070	+ .70	18	64
4 days.....	- .0170	-1.70	27	35
14 days.....	+ .0060	+ .40	32	41
Total loss in 21 days.....		0.13		

Changes in moisture content of sample (No. 1639 C) of well-dried Illinois coal—Continued.

SECOND SERIES—10 GRAMS ON 4-INCH WATCH GLASS.

Time interval between weighings.	Loss or gain in weight.		Air of laboratory.	
	Grams.	Per cent.	Temperature.	Humidity.
5 minutes.....	-0.0190	-0.19	28	36
6 minutes.....	- .0120	- .12		
15 minutes.....	- .0175	- .175		
1 hour.....	- .0280	- .28		
23 hours.....	+ .1235	+1.24	25	63
2 days.....	+ .0195	+ .20	18	64
4 days.....	- .0580	- .58	27	35
14 days.....	- .0280	- .28	32	41
Total loss in 21 days.....		0.18		

THIRD SERIES—8.3 GRAMS IN OPEN, WIDE-MOUTHED 2-OUNCE BOTTLE.

10 minutes.....	+0.0015	+0.02	23	69
20 minutes.....	+ .0010	+ .01		
20 minutes.....	- .0000			
5½ hours.....	+ .0080	+ .08	25	63
2 days.....	+ .0230	+ .29	18	64
Stirred.....	- .0000			
4 days.....	+ .0240	.29	27	35
14 days.....	- .0175	- .21	32	41
Stirred.....	- .0000	- .00		
Total gain in 20 days.....		0.48		

An inspection of these results shows that in samples of fine coal prepared from coal not previously air dried the loss may be rapid, being in a 1-gram portion of undried sample over 2 per cent in five minutes and over 8 per cent in twenty-four hours. That samples kept in bottles may lose a considerable amount of moisture unless tightly stoppered is also shown by the results obtained from weighing the samples in an open bottle, the loss in twenty-four hours being nearly

As might be expected, the rapidity of gain or loss is greatest in the 1-gram sample and least in the sample kept in an open bottle. A comparison of these losses after seventy-two days on the undried samples shows, however, that even in that time the loss on the 1-gram sample is decidedly in excess of that on the 10-gram sample, and about twice that on the sample in the open bottle. This result would lead to the inference that the change in weight is not due entirely to moisture losses, but is influenced more or less by oxidation changes. That such is the case is shown by the results of tests of the gain or loss in weight, from time to time, of fine samples kept in tightly stoppered bottles, moisture determinations being made at the same time to find out whether the amount of moisture present in the sample varies with the change in weight. These tests are described under "Alteration of weight of samples of coal when kept in a finely powdered state," pages 19-22.

COMPARISON OF EFFECTS OF DIFFERENT DRYING REAGENTS USED IN
THE DESICCATORS EMPLOYED IN MOISTURE DETERMINATIONS.

In the determinations of moisture made during the Louisiana Purchase Exposition and during the earlier part of 1905 duplicate results often were not as close as was desirable. This lack of agreement was found to be due, in part at least, to the use of calcium chloride as a drying reagent in the desiccators in which the fine samples of coal were allowed to cool after drying at 105° C., as may be seen from inspection of the following table giving the values obtained over concentrated sulphuric acid, fused calcium chloride, and granular calcium chloride.

Certain values from samples allowed to stand overnight, which are marked with a star (*), were on different gram portions of the sample. The values given for the other determinations, weighed as soon as cooled and weighed after standing in the desiccator overnight, are on the same weighed-out portions of the sample, which, as soon as weighed the first time, were put back in the desiccator and allowed to stand until the next day and then again weighed. The values over sulphuric acid are, as a rule, about one-tenth of 1 per cent lower on the sample after standing overnight, but this result can probably be accounted for by the small amount of moisture which might be taken up by the sample during the time required for making the first weighing.

Moisture determinations obtained by the use of different drying reagents.

Laboratory number.	Sample of coal. Field number.	Concentrated H_2SO_4 .		CaCl ₂ , fused.		CaCl ₂ , granular.	
		1. <i>a</i>	2. <i>b</i>	1. <i>a</i>	2. <i>b</i>	1. <i>a</i>	2. <i>b</i>
1660	Illinois No. 11 B	3.46		3.42		3.38	
1786	Illinois No. 13	3.92		3.38		3.40	
1802	Illinois No. 11 D	6.34		6.26			
1801	Illinois No. 7 D	2.74				2.74	
1803	Illinois No. 13	7.62		7.46			
1804	do	4.74		4.80			
1794	Alabama	1.38		1.18			
1798	Illinois No. 13	4.96				4.80	
1812	do	3.56		3.46			
1817	Indian Territory	1.42				1.30	
1828	Indiana No. 8	3.62		3.46			
1835	Brazil	4.99	4.92			4.91	4.58
1837	Illinois No. 7 D	3.60	3.60	3.55	3.23		
1807	Indiana No. 4	4.94				4.88	
1808	Illinois No. 12	5.90				5.82	
1836	Illinois No. 13	2.76				2.70	
1838	Illinois No. 18					5.08	
1842	Illinois No. 7 D	1.06		1.02			
1843	Colorado					7.98	7.40
1845	Illinois No. 11 D			4.12	3.46		
1846	Illinois No. 7 D	6.98	6.88	6.90	6.36		
1855	Illinois No. 11 D	1.24	1.14			1.14	.94
1844	Indiana No. 4	3.60				3.56	
1741	Illinois No. 18			3.32	2.58*		
1743	Indian Territory			2.36	1.38*		
1745	do			3.38	2.76*		
1753	Illinois No. 14			12.09	11.58*		

a Weighed as soon as cooled.

b Weighed after standing in desiccator overnight.

The values obtained over both granular and fused calcium chloride, where the sample was weighed as soon as cooled, are but little lower than the values obtained over sulphuric acid; but the values from the samples over calcium chloride when allowed to stand overnight are

RESULTS OBTAINED FOR MOISTURE.

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Moisture determinations on Illinois coal (percentages).

Details of treatment.	1-gram sample.	1-gram sample.	2-gram sample.
Loss after 15 minutes' heating at 100° to 107°.....	8.42	6.65	5.94
Additional loss after another 15 minutes' heating at 100° to 107°.....	.84	2.62	2.70
Total loss after 30 minutes' heating.....	9.26	9.27	8.64
Additional loss after heating another 30 minutes at 100° to 107°.....	.06	.16	.43
Total loss after 1 hour's heating.....	9.32	9.43	9.07
Gain in weight by standing uncovered 41 hours.....	3.68	3.68	3.55
Total loss after heating another 30 minutes.....	8.86	9.20	9.27
Gain in weight after standing 41 hours and reheating as compared with the value at the end of 1 hour's heating.....	.46	.28	.10

Moisture determinations on Indiana coal (percentages).

Details of treatment.	1-gram sample.	1-gram sample.	2-gram sample.	4-gram sample.
Loss after 30 minutes' heating at 105°.....	5.50	5.60 to 5.58	5.62 to 5.61	5.49
Additional loss after another 30 minutes at 105°.....	.01	.08 to .04	.07 to .02	.15
Total loss after 1 hour's heating.....	5.54	5.68 to 5.62	5.69 to 5.63	5.64
Gain in weight by standing uncovered 20 hours.....	3.44	3.43 to 3.35	3.41 to 3.35	3.34
Total loss after heating another hour at 105°.....	5.20	5.45 to 5.37	5.53 to 5.48	5.55
Gain in weight after 20 hours' standing and 1 hour's reheating compared with weight after first hour's heating.....	.31	.23 to .25	.16 to .15	.09
Gain in weight by standing uncovered 120 hours.....	3.06	3.12 to 2.95	3.15 to 3.11	3.12
Total loss after heating another hour at 105°.....	4.90	5.14 to 5.10	5.19 to 5.17	5.21
Gain in weight compared with weight after the first hour's heating.....	.64	.54 to .52	.50 to .46	.43
Gain in weight by standing uncovered 24 days.....	3.70	3.62 to 3.58	3.52 to 3.51	3.45
Total loss after another hour's heating at 105°.....	4.20	4.60 to 4.62	4.72 to 4.70	4.77
Gain in weight compared with weight after first hour's heating.....	1.34	1.06 to 1.00	.97 to .93	.67

These results show that practically all of the moisture is expelled from coals of these kinds during the first thirty minutes, and, furthermore, that there was an appreciable amount of oxidation in the sample during standing or from reheating. For short periods this oxidation, value in these experiments was apparently a surface reaction, dependent on the surface exposure of the sample and not on the amount. The samples were all weighed out in porcelain crucibles of the same size, and the amount of sample directly exposed was practically the same in all. In this case the percentage effect of equal oxidation on the Illinois samples would be in the ratio of 4, 2, and 1. The gains actually determined at the end of 41 hours were 0.46, 0.23, and 0.10 per cent, respectively, which are very close to this ratio.

On the Indiana sample the gains for oxidation at the end of twenty hours were 0.34, 0.24, 0.15, and 0.09 per cent, respectively. At the end of twenty-four days the percentages of gain on the different amounts are more nearly the same, but the gain is still greatest on the 1-gram sample and least on the 4-gram sample, the gains on the four amounts taken being 1.34, 1.04, 0.95, and 0.87 per cent, respectively.

ALTERATION OF WEIGHT OF SAMPLES OF COAL WHEN KEPT IN A FINELY POWDERED STATE.

In order to investigate the question of the extent of alteration of the samples when kept in a finely powdered condition as prepared for analysis, portions of a number of such samples were put in weighed

bottles, which were securely closed with rubber stoppers. These bottles were kept in the laboratory and weighed from time to time. Moisture determinations were made on portions of the sample at the times of the weighings, allowance being made for the portions removed for this purpose. The following table gives the percentage of moisture originally present in the sample, the percentage of gain or loss in weight at the several weighings, and the time interval between the weighings; also the total time covered by the experiment:

Alteration of weight of finely powdered coal.

[Minus sign denotes loss.]

Sample of coal.		Days between weighings.	Change in weight.	Moisture determination.
Laboratory number.	Field number.			
1635	Illinois No. 9 A.		<i>Per cent.</i>	<i>Per cent.</i>
		4	0.17	5.10
		20	.47	5.13
		42	.46	5.31
		25	.19	5.36
		172	.00	5.29
		124	-.33	4.99
	387	.96	4.38	
1638 C	Illinois No. 9 B.			12.34
		4	.16	12.58
		19	.45	12.12
		27	.22	12.03
		41	.23	11.79
		172	.00	11.62
		263	1.06	11.62
1638 E	do.			11.89
		4	.17	11.97
		46	1.07	11.80

ALTERATION OF WEIGHT OF SAMPLES.

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Alteration of weight of finely powdered coal—Continued.

[Minus sign denotes loss.]

Laboratory number.	Sample of coal. Field number.	Days between weighings.	Change in weight.	Moisture determination.
			Per cent.	Per cent.
2302	Ohio No. 5.....	9	.22	1.90
		18	.22	
		149	.40	2.40
		108	.13	2.48
		284	.97	.44
2131	Wyoming No. 2.....	2	.04	4.65
		3	.06	
		24	.18	
		7	.10	
		43	.09	
		28	.00	
		55	.06	4.55
		107	.02	4.46
2343	North Dakota No. 3.....	269	.55	-1.19
		4	.05	26.64
		3	.08	
		7	.06	
		43	.28	
		28	.07	
		55	.16	25.81
		107	.05	25.64
2275	Wyoming No. 2 B.....	247	.57	-1.00
		2	.05	6.37
		7	.05	
		43	.13	
		28	.02	
		55	.06	6.15
2278	Wyoming No. 3.....	135	.31	-.22
		2	.09	12.50
		7	.22	
		43	.68	
		28	.15	
		55	.38	11.97
2255	North Dakota No. 3.....	107	.26	11.81
		242	1.78	-.78
		2	.02	12.62
		5	.17	
		43	.34	
		28	.15	
2718	Texas No. 4.....	56	.16	12.86
		131	.84	.24
		6	.29	33.00
		42	.21	
		3	.03	32.87
		51	.56	-.13
2828	Massachusetts pent.....	127	-.66	13.60
		8	.07	
		13	.09	
		3	.00	13.72
		103	-.72	13.16
		127	-.66	-.44

Without exception these samples all increased in weight upon standing. At the same time the moisture values usually decreased. The gain in weight is to be ascribed to oxidation, and the decrease in moisture either to actual loss or to fixation of a portion of the moisture present by the oxidation changes. If the moisture loss be considered as an actual escape of moisture from the sample, the total gain due to oxidation is equal to the observed gain plus an amount equal to this moisture loss. The table below gives the total oxidation changes considered on this basis, together with the original and final calorimeter determinations on some of the samples, also the loss in calorific value in excess of that due merely to changes in weight of the sample. For purposes of comparison the amounts of moisture, ash, and sulphur present in the sample are also given.

Table showing oxidation, calorific value, moisture, ash, and sulphur.

(Minus sign denotes loss.)

Sample tested.		Calorific value.			Moisture.	Ash.	Sulphur.
Label number.	Field number.	Increase in weight due to oxida- tion.	Original.	Final.			
			Calories.	Calories.	Per cent.	Per cent.	Per cent.
1837	Illinois No. 9 A	1.58	.....	.....	4.36	11.40	4.43
1838	Illinois No. 9 B	1.78	.....	.....	12.34	.....	.....
1839	 50	1.47	.....	.....	11.59	.....	.....
1840	 50	1.84	.....	.....	4.35	11.48	4.40
1841	Illinois No. 11 B	1.58	.....	.....	4.25	12.38	2.62
1842	Illinois No. 4	1.82	4,428	4,285	5.56	16.95	2.59
2020	Massachusetts peat	1.00	4,055	4,049	35	20.74	.56
2217	North Dakota No. 2	1.37	4,498	4,431	3	25.54	1.32

DETERMINATIONS OF SPECIFIC GRAVITIES OF THE COALS.

Two determinations of specific gravity were made on a number of lumps about 1 inch in diameter. The first determination was made upon a number of specially selected lumps representing as clean coal as could be picked out, carefully avoiding portions contaminated with slate or pyrites; the second was made upon a number of lumps selected to represent the average quality of the coal as nearly as could be expected in pieces of this size. The determinations of each kind were made (in duplicate and sometimes in triplicate) with a large Nicholson's hydrometer designed for use with the coke samples and capable of handling 1,000 grams of coal. The following table gives the results on the two kinds of lumps. For ease of reference and for comparison the determinations of ash and sulphur on the car samples of each coal are also tabulated.

Determinations of ash, sulphur, and specific gravity.

Designation of coal sampled.	Car sample.		Specific gravity.	
	Ash.	Sulphur.	Selected lumps.	Average lumps.
Alabama No. 2 B.....	14.59	1.12	1.32	1.37
Alabama No. 3.....	14.36	.65	1.30	1.35
Alabama No. 4.....	12.92	1.05	1.28	1.32
Arkansas No. 7 A.....	11.69	2.02	1.32	1.44
Brazil.....	21.98	2.72	1.37	1.49
Illinois No. 19 B.....	9.36	.91	1.31	1.33
Illinois No. 23 A.....	11.53	4.41	1.22	1.28
Illinois No. 25.....	13.40	4.76	1.26	1.30
Illinois No. 26.....	12.09	3.51	1.22	1.31
Illinois No. 27.....	13.77	4.05	1.24	1.28
Indiana No. 5.....	10.88	4.27	1.28	1.42
Indiana No. 6.....	12.62	4.39	1.25	1.39
Indiana No. 7 A.....	9.21	3.74	1.27	1.40
Indiana No. 8.....	10.61	3.72	1.29	1.30
Indiana No. 9 A.....	10.30	3.27	1.25	1.36
Indiana No. 9 B.....	10.76	3.15	1.25	1.33
Indiana No. 10.....	8.57	3.83	1.24	1.29
Indiana No. 11.....	8.14	1.41	1.26	1.30
Indiana No. 12.....	11.65	3.87	1.26	1.32
Kansas No. 6.....	15.72	3.72	1.23	1.34
Kentucky No. 1 B.....	3.37	.88	1.27	1.40
Kentucky No. 5.....	3.70	.67	1.29	1.30
Kentucky No. 6.....	2.76	.57	1.27	1.28
Kentucky No. 7.....	9.48	3.60	1.31	1.44
Maryland No. 1.....	13.13	1.49	1.36	1.41
Missouri No. 6.....	11.74	5.60	1.21	1.36
New Mexico No. 3.....	16.67	.73	.29	1.37
New Mexico No. 4 A.....	14.57	.61	1.30	1.39
New Mexico No. 5.....	14.57	.69	1.31	1.35
North Dakota No. 1 B.....	11.42	3.54	1.25	1.44
North Dakota No. 3.....	7.75	1.15	a 1.22	
Ohio No. 1.....	11.95	4.61	1.29	1.35
Ohio No. 2.....	11.33	4.02	1.31	1.36
Ohio No. 3.....	11.58	1.81	1.30	1.33
Ohio No. 4.....	9.12	3.47	1.30	1.39
Ohio No. 5.....	7.30	1.72	1.29	1.33
Ohio Nos. 6 A, 6 B.....	8.52	3.33	1.29	1.35
Ohio No. 7.....	6.37	2.16	1.30	1.34
Ohio No. 8 A.....	8.37	2.84	1.30	1.42
Ohio No. 9 A.....	8.29	3.15	1.29	1.31
Ohio No. 9 B.....	11.93	3.35	1.30	1.36
Pennsylvania No. 4.....	10.41	1.26	1.30	1.35
Pennsylvania No. 5 A.....	6.02	1.20	1.30	1.31
Pennsylvania No. 5 B.....	6.05	.88	1.28	1.33
Pennsylvania No. 6.....	13.00	1.95	1.30	1.33
Do.....	12.52	1.94	1.30	1.38
Pennsylvania No. 7 A, 7 B.....	12.47	2.08	1.33	1.41
Pennsylvania No. 8.....	6.63	.94	1.31	1.36
Pennsylvania No. 9.....	11.33	2.04	1.35	1.39

a No distinction made between clean or selected lumps and average lumps.

Determinations of ash, sulphur, and specific gravity—Continued.

Designation of coal sampled.	Car sample.		Specific gravity.	
	Ash.	Sulphur	Selected lumps.	Average lumps.
Pennsylvania No. 10.....	6.17	1.26	1.80	1.36
Tennessee No. 2.....	6.81	.98	1.28	1.33
Tennessee No. 3.....	7.05	.99	1.29	1.32
Tennessee No. 4.....	9.53	.98	1.29	1.37
Tennessee No. 6.....	14.43	.78	1.29	1.31
Tennessee No. 7 A.....	12.85	3.26	1.34	1.89
Tennessee No. 8 A.....	13.42	4.38	1.34	1.37
Tennessee No. 10.....	59.14	.21	1.35	
Texas No. 3.....	7.84	.99		1.25
Texas No. 4.....	7.30	.51		1.26
Virginia No. 1 A.....	4.73	1.20	1.27	1.30
Virginia No. 1 B.....	5.01	1.11	1.27	1.34
Virginia No. 2 B.....	5.58	.92	1.28	1.37
Virginia No. 3.....	4.48	.67	1.27	1.28
Virginia No. 4.....	4.33	.79	1.28	1.28
Washington No. 1 B.....	11.87	.72	1.28	1.33
Washington No. 2.....	12.26	.38	1.32	1.39
West Virginia No. 4 B.....	7.76	.81	1.31	1.35
West Virginia No. 13.....	3.91	.89	1.27	1.30
West Virginia No. 14.....	3.27	1.03	1.27	1.28
West Virginia No. 15.....	8.55	2.54	1.28	1.31
West Virginia No. 16 A.....	5.57	1.06	1.30	1.37
West Virginia No. 16 B.....	8.37	1.20	1.28	1.34
West Virginia No. 17.....	8.12	1.45	1.28	1.41
West Virginia No. 18.....	5.83	.67	1.30	1.34
West Virginia No. 19.....	5.01	.89	1.26	1.38
West Virginia No. 20.....	8.03	1.38	1.27	1.34
West Virginia No. 21.....	4.85	1.32	1.28	1.34
Wyoming No. 2 B.....	20.79	4.03	1.31	1.37
Wyoming No. 3.....	16.70	6.66	1.23	1.40
Wyoming No. 4.....	6.77	.26	1.33	1.35
Wyoming No. 5.....	3.41	.81	1.26	1.30
Wyoming No. 6.....	3.12	.49	1.28	

It is obvious from the foregoing table that the specific gravity of the lumps of coal is considerably affected by the amount of impurities contained. Even the selected lumps were not free from ash and sulphur, so that it is not possible to obtain the true specific gravity of the pure coal itself.

1.65 specific gravity with the coal that sank. Each product was washed, air dried, and analyzed.

The results are given in the following table. Column 1 gives the percentage that the amount of coal in each grade of fineness forms of the entire sample treated; column 2, the percentage that the amount of coal in each class separated by gravity forms of the amount in its grade of fineness, and column 3, the percentage that the amount of coal in each class forms of the entire sample. Column 4 gives the determination of the ash in each class, expressed as a percentage of the amount of coal in the class; column 5, this determination of the ash expressed as a percentage of the entire sample of coal, and columns 6 and 7 give the same percentages for the sulphur. The totals of the results for ash and sulphur, in columns 5 and 7, should obviously equal the ash and sulphur determinations, respectively, in the original coal, which are printed below them for purposes of comparison. The differences are due to unavoidable errors in the work and, in some cases, probably in part to the presence of sulphates extracted in washing.

Impurities in coal as related to different grades of fineness and classes of specific gravity.

NO. 2023, BRAZIL NO. 1.^a

Grade and class of coal.	Mechanical distribution of coal.			Amount of ash in each class.		Amount of sulphur in each class.	
	Per cent of entire sample in each grade.	Amount in each class.		As per cent of coal in the class.	As per cent of entire sample of coal.	As per cent of coal in the class.	As per cent of entire sample of coal.
		Per cent of its own grade.	Per cent of entire sample.				
	1.	2.	3.	4.	5.	6.	7.
Dust (80 to 40)	3.95 3.05	51.43 43.57	.....	28.64 26.35	1.131 .804	1.90 1.60	0.075 .049
Sum	7.00	100.00	7.00				
Fine, 40 to 10	18.10						
Specific gravity—							
Under 1.35		62.11	11.15	11.64	1.298	.61	.068
1.35 to 1.45		2.23	.40	15.33	.061	.84	.003
1.45 to 1.65		17.83	3.20	30.22	.967	.615	.020
Above 1.65		17.83	3.20	54.49	1.744	5.41	.173
Sum		100.00	17.95				
Medium, 10 to 4	30.45						
Specific gravity—							
Under 1.35		55.53	17.56	13.90	2.439	.60	.105
1.35 to 1.45		3.64	1.15	23.38	.269	.59	.007
1.45 to 1.65		28.01	8.85	33.38	2.954	.55	.049
Above 1.65		12.82	4.05	55.08	2.231	8.92	.361
Sum		100.00	31.60				
Coarse, 4 to 2	44.60						
Specific gravity—							
Under 1.35		45.10	21.20	17.33	3.674	.64	.136
1.35 to 1.45		3.19	1.50	26.52	.398	.60	.007
1.45 to 1.65		31.92	15.00	32.74	4.911	.66	.099
Above 1.65		19.79	9.30	59.08	5.494	21.24	1.975
Sum		100.00	47.00				
Total	100.15		103.55		28.375		3.127
Original sample					28.18		3.28

^aSp. gr. of average

ull. 323—07—4

*Impurities in coal as related to different grades of fineness, etc.—Continued.*NO. 2346, MARYLAND NO. 1.^a

Grade and class of coal.	Mechanical distribution of coal.			Amount of ash in each class.		Amount of sulphur in each class.	
	Per cent of entire sample in each grade.	Amount in each class.		As per cent of coal in the class.	As per cent of entire sample of coal.	As per cent of coal in the class.	As per cent of entire sample of coal.
		Per cent of its own grade.	Per cent of entire sample.				
	1.	2.	3.	4.	5.	6.	7.
Dust {80.....	5.05	52.06	.....	15.47	0.781	2.00	0.101
{80 to 40.....	4.65	47.94	.....	12.99	.604	1.65	.072
Sum.....	9.70	100.00	9.70				
Fine, 40 to 10.....	33.45						
Specific gravity—							
Under 1.35.....		81.40	27.10	6.25	1.694	.92	.249
1.35 to 1.45.....		10.07	3.35	13.62	.456	1.25	.042
1.45 to 1.65.....		3.75	1.25	25.02	.313	2.21	.028
Above 1.65.....		4.78	1.60	61.48	.984	9.04	.145
Sum.....		100.00	33.30				
Medium, 10 to 4.....	41.95						
Specific gravity—							
Under 1.35.....		63.60	26.65	5.57	1.484	.84	.224
1.35 to 1.45.....		25.54	10.70	13.77	1.473	1.21	.129
1.45 to 1.65.....		5.85	2.45	25.63	.628	2.36	.058
Above 1.65.....		5.01	2.10	57.68	1.210	8.14	.171
Sum.....		100.00	41.90				
Coarse, 4 to 2.....	14.70						
Specific gravity—							
Under 1.35.....		39.15	5.75	6.45	.371	.84	.048
1.35 to 1.45.....		38.10	5.60	14.16	.793	1.07	.060
1.45 to 1.65.....		10.84	1.60	25.68	.411	2.48	.040
Above 1.65.....		11.91	1.75	55.90	.978	7.28	.127
Sum.....		100.00	14.70				
Total.....	99.80		99.60		12.180		1.49
Original sample.....					12.53		1.51

NO. 2308, PENNSYLVANIA NO. 6.^b

*Impurities in coal as related to different grades of fineness, etc.—Continued.*NO. 2298, WEST VIRGINIA NO. 15.^a

Grade and class of coal.	Mechanical distribution of coal.			Amount of ash in each class.		Amount of sulphur in each class.	
	Per cent of entire sample in each grade.	Amount in each class.		As per cent of coal in the class.	As per cent of entire sample of coal.	As per cent of coal in the class.	As per cent of entire sample of coal.
		Per cent of its own grade.	Per cent of entire sample.				
	1.	2.	3.	4.	5.	6.	7.
Dust, 80.....	5.35	55.15	5.35	10.35	0.554	3.42	0.183
80 to 40.....	4.35	44.85	4.35	8.27	.360	3.10	.116
Sum.....	9.70	100.00	9.70				
Fine, 40 to 10.....	22.65						
Specific gravity—							
Under 1.35.....		92.68	20.90	4.39	.917	1.62	.308
1.35 to 1.45.....		1.33	.30	13.63	.041	6.37	.019
1.45 to 1.65.....		.89	.20	22.75	.046	10.10	.020
Above 1.65.....		5.10	1.15	57.78	.671	26.95	.310
Sum.....		100.00	22.55				
Medium, 10 to 4.....	33.20						
Specific gravity—							
Under 1.35.....		90.65	30.05	4.56	1.370	1.59	.478
1.35 to 1.45.....		3.77	1.25	13.40	.167	6.48	.081
1.45 to 1.65.....		1.81	.60	22.89	.137	10.25	.061
Above 1.65.....		3.77	1.25	53.03	.663	26.26	.328
Sum.....		100.00	33.15				
Coarse, 4 to 2.....	34.30						
Specific gravity—							
Under 1.35.....		86.30	29.60	5.40	1.597	1.73	.512
1.35 to 1.45.....		6.42	2.20	13.10	.288	6.40	.141
1.45 to 1.65.....		3.49	1.20	24.88	.298	7.40	.089
Above 1.65.....		3.79	1.30	66.15	.860	15.05	.171
Sum.....		100.00	34.30				
Total.....	99.85		99.70		7.969		2.846
Original sample.....					7.34		2.82

NO. 2278, WYOMING NO. 3.^b

Dust, 80.....	2.05	54.62	.....	23.45	0.481	8.89	0.182
80 to 40.....	1.70	45.38	.....	19.43	.330	8.21	.139
Sum.....	3.75	100.00	3.75				
Fine, 40 to 10.....	11.50						
Specific gravity—							
Under 1.35.....		74.12	8.30	5.46	.453	4.91	.407
Above 1.35.....		25.88	2.90	47.51	1.378	14.43	.418
Sum.....		100.00	11.20				
Medium, 10 to 4.....	29.85						
Specific gravity—							
Under 1.35.....		77.03	22.65	5.54	1.255	4.72	1.069
Above 1.35.....		22.97	6.75	47.98	3.239	15.54	1.049
Sum.....		100.00	29.40				
Coarse, 4 to 2.....	54.85						
Specific gravity—							
Under 1.35.....		69.65	38.20	6.53	2.494	4.66	1.780
Above 1.35.....		30.35	16.65	50.03	8.330	18.04	3.004
Sum.....		100.00	54.85				
Total.....	99.95		99.20		17.960		8.048
Original sample.....					17.96		8.36

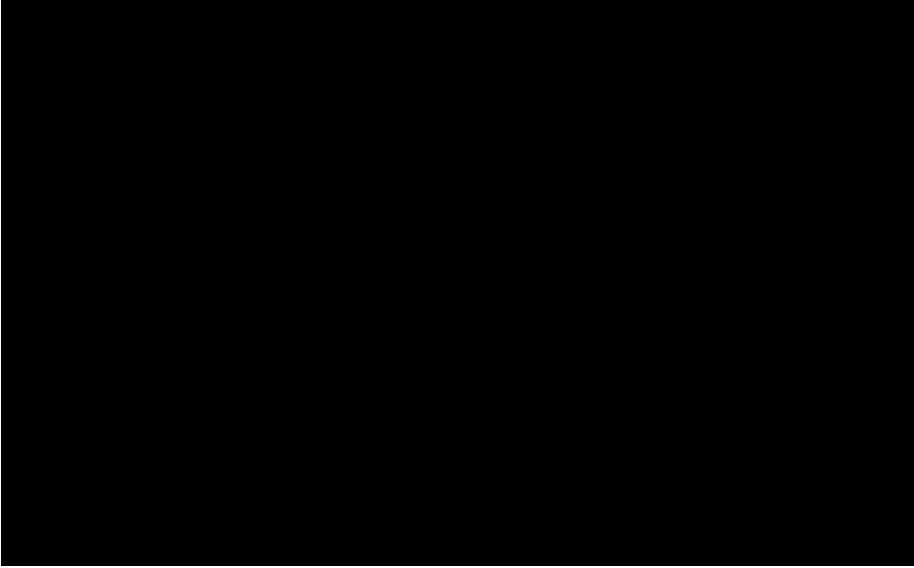
^aSp. gr. of average lumps, 1.31; of selected lumps, 1.28.^bSp. gr. of average lumps, 1.40; of

An examination of the figures in the foregoing table shows the very rapid increase in impurity of the coal with increase in specific gravity. The finer the coal is crushed the more complete would be the mechanical separation of the heavy impurities from the coal, but the behavior in this respect evidently varies greatly with different coals. In the Brazil coal the sulphur is nearly the same in all the coal under $\frac{1}{4}$ -inch size and below 1.65 specific gravity, while the ash increases both with size and with the specific gravity. In the Maryland coal both sulphur and ash increase with specific gravity, and apparently without very much reference to size of product. Practically the same is true of the Pennsylvania No. 6 coal and of the West Virginia coal. The record of the Wyoming coal is not sufficiently complete for comparison. In all but the Brazil coal there is a marked tendency to increase of ash and sulphur in the fine dust, suggesting that the impurities are liberated in crushing and are more brittle than the mass of the coal. Noticeably different compositions in ash and sulphur of the portions of the various coals below 1.35 specific gravity, may indicate either actual variations in the specific gravity of the coal proper or variations in the nature of the combination of the sulphur and mineral matter.

Further experiments along these lines seem very desirable.

LABORATORY METHODS OF DETERMINING ADAPTABILITY OF COALS TO IMPROVEMENT BY WASHING.

The laboratory method of testing consists in floating the sample upon solutions of different density and thereby separating the coal into portions of different specific gravity, the amounts of these portions being determined and each portion analyzed separately for ash



certain of the coals, are given in the tables of results below. As these laboratory samples were all crushed to one-half inch and finer before testing, these results do not necessarily show what might be done with the coal crushed to other sizes. They do, however, give an indication of the possible improvements which may be expected from washing.

The "one-fortieth inch and finer" portion of the sample was tested as follows: The sample was stirred up with water, and after settling for one minute the liquid was decanted off very closely and the remaining portion was dried, weighed, and analyzed. The loss on decantation indicates in a very general way the extent to which the coal breaks down into a fine powder upon handling or crushing, and is an indication of the amount of fine coal lost during washing. The particular crushing machinery used would, however, greatly affect the amount of fines produced in crushing. The analytical results on the portion remaining after decantation are in a general way an index to the way the impurities separate from the coal in crushing.

The interpretation of these results may perhaps be understood best by a consideration of the results derived from some particular sample, as Indiana No. 7 A. In this sample the ash and sulphur contents in the unwashed coal are, respectively, 9.03 and 3.75. The sample crushed to " $\frac{1}{4}$ inch to $\frac{1}{8}$ inch" was separated by sifting into 91.1 per cent coarse and 8.6 per cent fine. Considering the coarse portion: The part lighter than 1.35 specific gravity amounted to 86.7 per cent of the entire sample, and contained 6.69 per cent ash and 3.05 per cent sulphur. It is quite probable that in actual washing practice a large part of the " $\frac{1}{4}$ inch and finer" would be reduced in ash and sulphur contents to about the same percentage, which would indicate the possibility of improving this coal 2 per cent in ash and 0.7 per cent in sulphur, accompanied by a washing loss of about 10 per cent. The distribution of the ash and sulphur on the heavier portion is shown by the percentage results on the "1.35 to 1.65" portion and on the portion "Heavier than 1.65." The washery tests do not show so great an improvement in ash and sulphur as might be expected from the analysis of the portion "Lighter than 1.35," and a portion of the "1.35 to 1.65" specific gravity material evidently remained with the washed coal. However, washery tests upon such small lots of coal can not be expected to give the best results; also the possible improvement at $\frac{1}{4}$ -inch size is apt to be greater than can be obtained at $\frac{1}{8}$ -inch size, at which the sample was worked at the washery. The results of the laboratory tests indicate that the high sulphur and the comparatively high ash in the washed coal from the washery is not the fault of the washing, but is due to the combination in which the ash and sulphur occur, showing that a very low ash and sulphur product can not be obtained from this coal by washing. The laboratory tests do, how-

ever, indicate that under the best conditions of washing there would be some improvement, but not much, over the results obtained at the washery of the fuel-testing plant.

Determinations of ash and sulphur in coal samples variously treated.

ILLINOIS NO. 9 A.

[Unwashed coal—ash, 11.21; sulphur, 4.58.]

	Portion.	Ash.	Sulphur.	Compared with original sample.	
				Ash.	Sulphur.
First series:					
$\frac{1}{8}$ inch to $\frac{1}{16}$ inch.....	91.9				
Lighter than 1.35.....	75.2	6.08	3.16	4.57	2.38
1.35 to 1.65.....	12.1	21.04	4.80	2.55	.68
Heavier than 1.65.....	4.2	58.34	16.93	2.45	.71
$\frac{1}{16}$ inch and finer.....	9.0				
Very fine, decanted ^a	2.3			.26	.10
Remainder.....	5.6	13.88	4.20	.78	.24
				10.61	4.01
Second series:					
$\frac{1}{8}$ inch to $\frac{1}{16}$ inch.....	91.9				
Lighter than 1.45.....	84.9	8.22	3.32	6.96	2.82
Heavier than 1.45.....	7.7	44.02	14.12	3.39	1.09
$\frac{1}{16}$ inch and finer.....	7.7				
Very fine, decanted ^a	2.4			.27	.11
Remainder.....	5.6	13.88	4.20	.78	.24
				11.42	4.26
Washed at $\frac{1}{16}$ -inch size:					
Sample No. 1.....		8.14	3.63		
No. 2.....		8.26	3.71		

ILLINOIS NO. 11 B.

[Unwashed coal—ash, 12.54; sulphur, 2.86.]

$\frac{1}{8}$ inch to $\frac{1}{16}$ inch.....	80.1				
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Determinations of ash and sulphur in coal samples variously treated—Continued.

INDIANA NO. 4.

[Unwashed coal (boiler-test sample, No. 1892)—ash, 15.63; sulphur, 2.74.]

	Portion.	Ash.	Sulphur.	Compared with original sample.	
				Ash.	Sulphur.
$\frac{1}{4}$ inch to $\frac{3}{8}$ inch.....	81.9				
Lighter than 1.35.....	61.8	5.89	1.82	3.66	1.12
1.35 to 1.65.....	11.9	17.50	3.54	2.10	.42
Heavier than 1.65.....	8.9	69.29	7.01	6.17	.62
$\frac{3}{8}$ inch and finer.....	17.5				
Very fine, decanted <i>a</i>	5.3			.83	.15
Remainder.....	12.2	23.83	2.84	2.88	.35
Washed at $\frac{1}{4}$ -inch size:				15.64	2.66
Sample No. 1.....		8.26	2.26		
No. 2.....		7.69	2.26		

INDIANA NO. 6.

[Unwashed coal (boiler-test sample, No. 1928)—ash, 13.54; sulphur, 4.83.]

$\frac{1}{4}$ inch to $\frac{3}{8}$ inch.....	76.1				
Lighter than 1.35.....	56.2	6.63	2.92	3.73	1.64
1.35 to 1.65.....	13.6	19.58	5.54	2.66	.75
Heavier than 1.65.....	6.7	54.89	13.75	3.68	.91
$\frac{3}{8}$ inch and finer.....	23.2				
Very fine, decanted <i>a</i>	6.9			.93	.33
Remainder.....	16.3	17.10	5.19	2.79	.85
Washed at $\frac{1}{4}$ -inch size:				13.79	4.48
Sample No. 1.....		10.34	3.67		
No. 2.....		10.98	3.94		
No. 3.....		10.06	3.73		

INDIANA NO. 7 A.

[Unwashed coal (boiler-test sample, No. 1939)—ash, 9.03; sulphur, 3.75.]

$\frac{1}{4}$ inch to $\frac{3}{8}$ inch.....	91.1				
Lighter than 1.35.....	86.7	6.69	3.05	5.80	2.64
1.35 to 1.65.....	3.6	26.23	4.39	.94	.16
Heavier than 1.65.....	3.4	55.84	23.48	1.90	.80
$\frac{3}{8}$ inch and finer.....	8.6				
Very fine, decanted <i>a</i>	5.4			.49	.20
Remainder.....	3.2	17.13	4.48	.55	.14
Washed at $\frac{1}{4}$ -inch size:				9.68	3.94
Sample No. 1.....		8.94	3.33		
No. 2.....		8.18	3.36		

INDIANA NO. 9 B.

[Unwashed coal (boiler-test sample, No. 2035)—ash, 10.98; sulphur, 3.02.]

$\frac{1}{4}$ inch to $\frac{3}{8}$ inch.....	78.4				
Lighter than 1.35.....	64.2	8.04	2.30	5.16	1.48
1.35 to 1.65.....	7.3	25.90	4.60	1.89	.33
Heavier than 1.65.....	3.2	60.75	16.70	1.94	.52
$\frac{3}{8}$ inch and finer.....	21.3				
Very fine, decanted <i>a</i>	8.8			.97	.26
Remainder.....	12.5	19.87	4.24	2.48	.53
Washed at $\frac{1}{4}$ -inch size:				12.44	3.12
Sample No. 1.....		9.22	2.91		
No. 2.....		8.54	2.69		

a Estimated from results on unw

EXPERIMENTAL WORK IN FUEL TESTING.

Determinations of ash and sulphur in coal samples variously treated—(Continued).

INDIANA NO. 11.

[Unwashed coal (boiler-test sample, No. 2421)—ash, 8.60; sulphur, 1.61.]

	Portion.	Ash.	Sulphur.	Compared with original sample.	
				Ash.	Sulphur.
$\frac{1}{4}$ inch to $\frac{1}{2}$ inch.....	80.9				
Lighter than 1.35.....	72.4	6.10	1.22	4.42	0.88
1.35 to 1.65.....	4.9	25.90	2.78	1.27	.14
Heavier than 1.65.....	3.4	54.34	10.14	1.85	.34
$\frac{1}{8}$ inch and finer.....	18.7				
Very fine, decanted.....	9.7			.83	.16
Remainder.....	9.0	13.69	2.30	1.25	.21
				9.62	1.73

KENTUCKY NO. 6.

[Unwashed coal (boiler-test sample, No. 2662)—ash, 3.15; sulphur, 0.44.]

$\frac{1}{4}$ inch to $\frac{1}{2}$ inch.....	89.8				
Lighter than 1.35.....	88.4	2.27	0.56	2.01	0.50
1.35 to 1.65.....	.6	27.50	.71	.15	.00
Heavier than 1.65.....	.6	71.61	.85	.43	.01
$\frac{1}{8}$ inch and finer.....	9.8				
Very fine, decanted.....	6.0			.19	.03
Remainder.....	3.9	6.85	.70	.27	.03
				3.05	.57

MISSOURI NO. 5.

[Unwashed (boiler-test sample, No. 2892)—ash, 16.94; sulphur, 5.60.]

$\frac{1}{4}$ inch to $\frac{1}{2}$ inch.....	91.5				
Lighter than 1.35.....	74.7	6.86	3.17	5.12	2.37
1.35 to 1.65.....	8.4	23.13	6.97	1.94	.56
Heavier than 1.65.....	9.4	55.85	16.28	5.25	1.53

Determinations of ash and sulphur in coal samples variously treated—Continued.

OHIO NO. 1.

[Unwashed coal (boiler-test sample, No. 2136)—ash, 16.91; sulphur, 5.34.]

	Portion.	Ash.	Sulphur.	Compared with original sample.	
				Ash.	Sulphur.
$\frac{1}{8}$ inch to $\frac{1}{4}$ inch.....	87.0				
Lighter than 1.35.....	57.5	5.97	2.91	3.45	1.67
1.35 to 1.65.....	16.8	18.91	5.87	3.18	.98
Heavier than 1.65.....	7.3	54.35	15.01	3.97	1.10
$\frac{1}{4}$ inch and finer.....	12.9				
Very fine, decanted ^a	7.3			1.25	.59
Remainder.....	5.6	29.56	7.04	1.69	.40
				13.50	4.54
Washed at 14-inch size:					
Sample No. 1.....		9.20	3.98		

OHIO NO. 5.

[Unwashed coal (boiler-test sample, No. 2101)—ash, 8.02; sulphur, 1.65.]

$\frac{1}{8}$ inch and $\frac{1}{4}$ inch.....	90.8				
Lighter than 1.35.....	78.1	4.77	1.39	3.73	1.09
1.35 to 1.65.....	7.5	17.33	2.63	1.30	.19
Heavier than 1.65.....	3.4	69.67	3.72	2.37	.13
$\frac{1}{4}$ inch and finer.....	8.9				
Very fine, decanted ^a	6.4			.51	.10
Remainder.....	2.6	12.70	2.74	.33	.07
				8.24	1.36

PENNSYLVANIA NO. 8.

[Unwashed coal (boiler-test sample, No. 2446)—ash, 6.33; sulphur, 0.89.]

$\frac{1}{8}$ inch to $\frac{1}{4}$ inch.....	78.5				
Lighter than 1.35.....	71.0	5.02	0.58	3.56	0.41
1.35 to 1.65.....	4.8	21.19	1.49	1.02	.07
Heavier than 1.65.....	1.6	51.98	8.36	.83	.13
$\frac{1}{4}$ inch and finer.....	21.2				
Very fine, decanted ^a	12.6			.80	.11
Remainder.....	8.6	7.51	1.10	.65	.09
				6.86	.81

PENNSYLVANIA NOS. 7 A AND 7 B.

[Unwashed coal (boiler-test sample, No. 2182)—ash, 11.36; sulphur, 1.68.]

$\frac{1}{8}$ inch to $\frac{1}{4}$ inch.....	90.6				
Lighter than 1.35.....	73.5	8.81	1.40	6.48	1.03
1.35 to 1.65.....	14.6	23.12	2.03	3.38	.30
Heavier than 1.65.....	1.1	13.65	9.71	.18	.11
$\frac{1}{4}$ inch and finer.....	9.0				
Very fine, decanted ^a	7.4			.84	.13
Remainder.....	1.7	12.53	3.39	.21	.06
				11.39	1.63
Washed at 14-inch size:					
Sample No. 1.....		10.62	1.63		
No. 2.....		11.36	1.68		

^a Estimated from results on unwashed coal.

EXPERIMENTAL WORK IN FUEL TESTING.

Determinations of ash and sulphur in coal samples variously treated—Continued.

PENNSYLVANIA NO. 10.

[Unwashed coal (boiler-test sample, No. 2373)—ash, 6.37; sulphur, 1.35.]

	Portion.	Ash.	Sulphur.	Compared with original sample.	
				Ash.	Sulphur.
$\frac{1}{4}$ inch to $\frac{1}{8}$ inch	87.0				
Lighter than 1.35	78.5	4.50	1.07	3.53	0.85
1.35 to 1.65	5.6	13.15	1.84	.75	.10
Heavier than 1.65	1.9	62.70	8.70	1.19	.17
$\frac{1}{8}$ inch and finer	12.7				
Very fine, decanted <i>a</i>	7.6			.48	.11
Remainder	5.0	9.49	2.27	.48	.11
				6.43	1.34

TENNESSEE NO. 6.

[Unwashed coal (boiler-test sample, No. 3102)—ash, 14.86; sulphur, 0.80.]

$\frac{1}{4}$ inch to $\frac{1}{8}$ inch	93.8				
Lighter than 1.35	71.5	3.42	0.67	2.45	0.7
1.35 to 1.65	7.7	20.64	1.18	1.59	.69
Heavier than 1.65	14.0	70.99	2.74	9.94	.38
$\frac{1}{8}$ inch and finer	5.9				
Very fine, decanted <i>a</i>	2.7			.40	.02
Remainder	3.3	22.75	1.08	.75	.04
				15.13	1.00

VIRGINIA NO. 4.

[Unwashed coal (boiler-test sample, No. 2533)—ash, 4.02; sulphur, 0.45.]

$\frac{1}{4}$ inch to $\frac{1}{8}$ inch	92.8				
Lighter than 1.35	88.3	1.93	0.48	1.70	0.41
1.35 to 1.65	3.3	15.61	.65	.90	.23
Heavier than 1.65	1.2	82.46	8.87	7.40	.36
$\frac{1}{8}$ inch and finer	7.0				
Very fine, decanted <i>a</i>	3.7			.40	.02
Remainder	3.3	22.75	1.08	.75	.04
				15.13	1.00

Determinations of ash and sulphur in coal samples variously treated—Continued.

WEST VIRGINIA NO. 13.

[Unwashed coal (boiler-test sample, No. 2058)—ash, 3.93; sulphur, 0.96.]

	Portion.	Ash.	Sulphur.	Compared with original sample.	
				Ash.	Sulphur.
$\frac{1}{8}$ inch to $\frac{1}{4}$ inch.....	93.6				
Lighter than 1.35.....	89.1	2.41	0.83	2.15	0.74
1.35 to 1.65.....	2.2	20.72	1.27	.46	.03
Heavier than 1.65.....	1.7	70.16	2.59	1.19	.04
$\frac{1}{4}$ inch and finer.....	6.1				
Very fine, decanted ^a	3.6			.14	.04
Remainder.....	2.5	9.64	1.08	.24	.06
				4.18	.88

WEST VIRGINIA NO. 14.

[Unwashed coal (boiler-test sample, No. 2052)—ash, 2.27; sulphur, 1.07.]

$\frac{1}{8}$ inch to $\frac{1}{4}$ inch.....	88.6				
Lighter than 1.35.....	84.4	1.52	0.88	1.28	0.74
1.35 to 1.65.....	1.0	14.52	2.11	.15	.02
Heavier than 1.65.....	1.0	58.60	13.45	.59	.13
$\frac{1}{4}$ inch and finer.....	11.1				
Very fine, decanted ^a	7.7			.17	.06
Remainder.....	3.4	7.10	1.89	.24	.07
				2.43	1.04

WEST VIRGINIA NO. 18.

[Unwashed coal (boiler-test sample, No. 2607)—ash, 6.21; sulphur, 0.67.]

$\frac{1}{8}$ inch to $\frac{1}{4}$ inch.....	91.0				
Lighter than 1.35.....	86.0	4.88	0.68	4.20	0.69
1.35 to 1.65.....	3.0	22.81	.50	.68	.02
Heavier than 1.65.....	1.0	62.55	.57	.63	.01
$\frac{1}{4}$ inch and finer.....	8.6				
Very fine, decanted ^a	6.1			.38	.04
Remainder.....	2.5	7.97	.83	.20	.02
				6.09	.68

WYOMING NO. 2 B.

[Unwashed coal (boiler-test sample, No. 2164)—ash, 21.38; sulphur, 4.41.]

$\frac{1}{8}$ inch to $\frac{1}{4}$ inch.....	94.0				
Lighter than 1.35.....	62.1	10.85	4.34	6.77	2.70
1.35 to 1.65.....	21.4	31.84	3.27	6.81	.70
Heavier than 1.65.....	12.1	64.30	6.48	7.78	.78
$\frac{1}{4}$ inch and finer.....	5.9				
Very fine, decanted ^a	3.3			.71	.15
Remainder.....	2.6	31.45	4.11	.82	.11
				22.89	4.44

^a Estimated from results on unwashed coal.

Determinations of ash and sulphur in coal samples variously treated—Continued.

SPECIAL TEST ON REFUSE FROM A WASHING.

(Original refuse—ash, 47.50; sulphur, 1.71.)

	Portion.	Ash.	Sulphur.	Compared with original sample.	
				Ash.	Sulphur.
$\frac{1}{2}$ inch to $\frac{1}{16}$ inch.....	85.2				
Lighter than 1.35.....	15.0	12.23	0.88	1.83	0.13
1.35 to 1.65.....	17.7	28.13	.76	4.96	.13
Heavier than 1.65.....	51.4	64.88	1.79	33.35	.92
$\frac{1}{16}$ inch and finer.....	14.5				
Very fine, decanted ^a	3.6			1.43	.05
Remainder.....	11.6	33.27	1.48	3.83	.17
				45.42	1.40

^a Estimated from results on original refuse.VOLATILE MATTER IN COALS AND LIGNITES.^a

The official method of determining volatile matter, recommended by the committee on coal analysis appointed by the American Chemical Society, is as follows:

Place 1 gram of fresh, undried, powdered coal in a platinum crucible weighing 20 or 30 grams and having a tightly fitting cover. Heat over the full flame of a Bunsen burner for seven minutes. The crucible should be supported on a platinum triangle, with the bottom 6 to 8 centimeters above the top of the burner. The flame should be fully 20 centimeters high when burning free, and the determination should be made in a place free from draughts. The upper surface of the cover should burn clear, but the under surface should remain covered with carbon. To find "volatile combustible matter," subtract the per cent of moisture from the loss found here.

This method has been used regularly in the volatile determinations

Laboratory analyses on samples 2734 and 2764 of Texas No. 3 lignite.

Constituent.	Samples.		
	2734.	2764.	
	1.	2.	3.
Moisture.....	9.88	20.24	20.24
Volatile matter.....	36.17	58.48	35.42
Fixed carbon.....	43.65	10.85	33.91
Ash.....	10.30	10.43	10.43
Sulphur.....	1.30	1.03	1.06

This great difference in the fixed-carbon results shown in columns 1 and 2 could not be accidental, as all of the determinations on both samples were duplicated. A series of determinations was begun, to learn, if possible, the cause of this great variation. The two following causes were suspected, both of which were found to be partly responsible for the difference: (1) Mechanical loss due to the throwing out of solid particles by the too rapid expulsion of the volatile matter. The possibility of loss from this source is mentioned in the report of the committee of the American Chemical Society, but the results of their experiments are negative. (2) A different breaking down of the hydrocarbon compounds when expelled under different conditions and in the presence of variable amounts of moisture.

The results of Mr. N. M. Austin's preliminary treatment of the sample with a low heat and then with the application of the full flame of the Bunsen burner gives higher results in fixed carbon than where the full flame of the Bunsen burner is applied from the beginning. The proximate analysis of sample 2764, giving the unusual results, which was finally reported by the laboratory, is shown in column 3.

A series of seven results by the official method gave for volatile matter on this sample an average of 62.5 per cent, with a variation between high and low results of over 12 per cent. Three results of volatile matter on this sample made after previous expulsion of the moisture at 105° C. gave average volatile matter 39.6 per cent, with a variation between high and low results of 5.9 per cent. Preliminary treatment by driving off the moisture and most of the volatile matter at a low heat was then tried, the flame of the Bunsen burner being turned down to 10 centimeters and the crucible gradually heated. The application of the heat was regulated by holding the burner in the hand and heating in such a way as to expel the moisture slowly and gradually smoke off most of the volatile matter, the volatile matter escaping freely enough during the last minute of this preliminary heating to burn with a small flame around the edge of the crucible cover. Two results with five minutes of preliminary heating and then seven minutes over the full flame of the Bunsen burner gave an average in volatile matter of 35.08 per cent, the variation between the two results being 0.23 per cent. Two results with three minutes' pre-

liminary heating and seven minutes over the full flame of the Bunsen burner gave an average of 35.6 per cent, with a variation of 0.75 per cent between results. A result obtained by four minutes of preliminary heating and then seven minutes over the full flame gave 35.42 per cent. The difference in results obtained by the three-, four-, and five-minute preliminary treatment is small, and in all subsequent experimental tests the time of the preliminary heating was four minutes. To determine the mechanical losses and difference in volatile compounds given off, a number of ash determinations were made after the driving off of the volatile matter by the official method and after driving off the volatile matter in connection with the preliminary heating. The results of volatile matter and ash on three determinations by the official method and on two determinations by the modified method of four minutes of preliminary heating and then seven minutes over the full flame are as follows:

Determinations of volatile matter by two methods.

Constituent.	Official method.			Modified method.	
	1.	2.	3.	4.	5.
Volatile matter.....	66.72	67.47	54.82	36.06	36.65
Ash.....	4.30	4.38	7.25	11.16	11.15

^a This result is possibly explained by the fact that this sample stood for two hours in the crucible after weighing out, and a considerable amount of the moisture content may have escaped before the sample was treated for the determination of the volatile matter.

That mechanical losses occurred during the rapid evolution of the volatile matter by the official method was also indicated by the shower

from the third result by the official method was 7.25 per cent, or the loss of ash 3.9 per cent. Correction for fixed carbon mechanically carried off is accordingly $3.9 \div 11.15$, or 35 per cent. This portion of the fixed carbon as shown by the modified method gives 11.4 per cent as the amount of fixed carbon expelled mechanically. The result, after making the fixed-carbon and ash corrections, is shown in column 2 of the following table:

Corrected determinations by the official method.

Constituent.	Corrected results.	
	1.	2.
Moisture.....	19.78	19.78
Volatile matter.....	47.10	43.42
Fixed carbon.....	21.97	25.65
Ash.....	11.15	11.15
	100.00	100.00

The difference in this case in fixed carbon, due to the different heat treatment, is 7.07 per cent.

This particular sample was very finely ground. To find out how much the difference in result was due to the fineness of grinding a duplicate portion of the same sample was ground down till it passed a 40-mesh sieve. The results of duplicates by the official method and by the modified method are shown in the next table. The proximate analysis of the first sample by the modified method is shown in column 2. The correction for fixed carbon to be applied to the result of the official method is $0.95 \div 11.20$, or 8.5 per cent of the fixed-carbon result of the modified method, which is 2.9 per cent. The results by the official method, after correcting for mechanical loss of fixed carbon and ash, are shown in column 1. The difference in fixed carbon between the two methods, due to different heat treatment, is 3.45 per cent. These results show, at least for lignites, that the fineness of the sample has an important effect. Upon a second sample of lignite, similar to the first except that it contained more moisture (30.45 per cent), the average results by the modified process are as tabulated in column 4. A comparison of the results in volatile matter and ash by the official method shows that the correction to be applied to the fixed carbon and ash for mechanical loss is $2.71 \div 10.83$. These corrections, as applied to the results obtained by the official method, are shown in column 3.

EXPERIMENTAL WORK IN FUEL TESTING.

Determinations on sample ground to pass a 40-mesh sieve.

Constituent.	First sample.		Second sample.	
	Official method.	Modified method.	Official method.	Modified method.
	1.	2.	3.	4.
Volatile matter	42.07	35.72	44.40	30.97
Ash	10.25	11.20	8.12	10.83
Loss in ash	.95		2.71	
Proximate analysis:				
Moisture	a 19.35	19.35	a 30.45	30.45
Volatile matter	a 39.17	35.72	a 37.43	30.97
Fixed carbon	a 30.28	33.73	a 21.29	27.75
Ash	a 11.20	11.20	a 10.83	10.83
	100.00	100.00	100.00	100.00

a After correcting for mechanical loss of fixed carbon and ash, the difference in the fixed-carbon results between the two samples, due to different heat treatment, is 6.46 per cent.

To test the effect of the fineness of grinding upon the determination of the volatile matter in ordinary bituminous coal, a sample of coal, Kentucky No. 1 C, containing 2 per cent moisture, 5.7 per cent ash, and 0.9 per cent sulphur, was still further reduced in ash content by floating on a calcium-chloride solution of 1.32 specific gravity. The lighter portion was then thoroughly air dried and separated by sifting into five sizes, and proximate analyses of the parts were made by the official method, with the following results:

Determinations for volatile matter on Kentucky No. 1 C coal.

Constituent.	Sizes of separation by sifting.				
	$\frac{1}{2}$ to $\frac{1}{10}$	$\frac{1}{10}$ to $\frac{1}{20}$	$\frac{1}{20}$ to $\frac{1}{40}$	$\frac{1}{40}$ to $\frac{1}{80}$	$\frac{1}{80}$ and finer.

volatile matter than the coarser samples, probably due to the more complete sintering together of the fine samples upon heating, with the consequent effect upon the giving off of the volatile matter.

In order to find out how much effect different heat treatment has on different fuels, a series of samples was selected ranging from anthracite to peat, most of the samples used in the tests having been previously more or less completely air dried so as to permit of better handling in the laboratory. Determinations for volatile matter were made in duplicate by the regular official method and by the modified method with four minutes' preliminary heating. The proximate analyses of the samples with the volatile matter determined by the official method are shown in columns 1 to 5 of the next table; the results for volatile matter by the preliminary heating are given in column 6; and the differences in volatile matter by the two methods are given in column 7. The determinations for moisture were all made in accordance with the official method, by weighing out a separate sample. The same is true of the determinations for ash, with the exception that upon two or three of the lignite samples and one of the Pennsylvania samples the results for ash are those obtained after the determination of the volatile matter by the modified process. These particular samples and results are all specifically mentioned elsewhere (p. 42).

Effect of different heat treatment on determination of volatile matter.

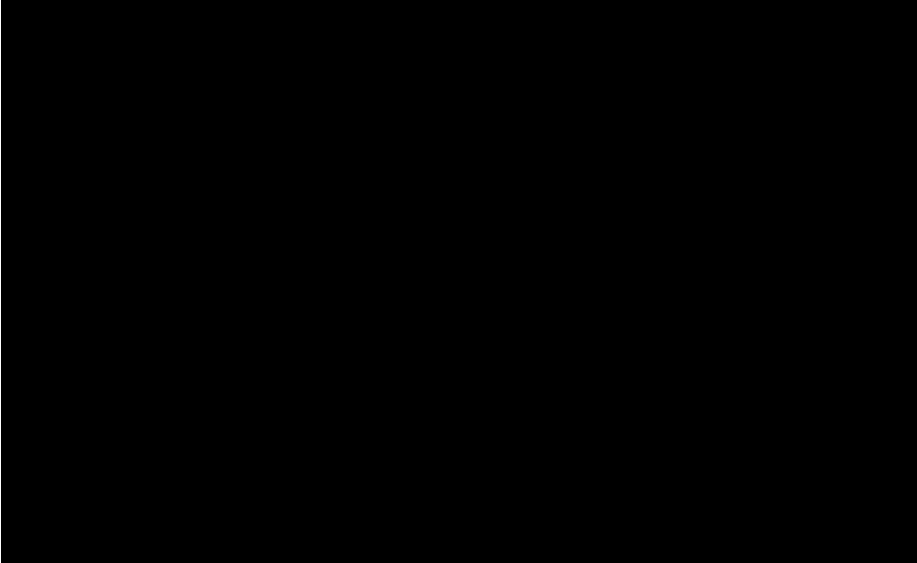
Fuel treated.	Proximate analysis (official method).					Volatile matter (modified method.)	Difference.
	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.		
	1.	2.	3.	4.	5.	6.	7.
Colorado anthracite.....	2.80	5.05	77.55	14.60	0.60	4.90	0.15
Arkansas.....	.83	12.47	72.05	14.65	2.14	12.37	.10
Pennsylvania.....	.90	17.35	74.92	6.83	.97	16.07	1.28
Do.....	1.05	33.10	53.30	12.55	1.76	30.35	2.75
Kentucky.....	2.99	37.51	56.68	2.82	.58	34.78	2.73
Indiana.....	4.20	37.70	45.65	12.45	4.13	34.67	3.03
Washington.....	6.65	35.87	44.57	12.91	.68	34.25	1.62
Indiana.....	8.40	34.40	48.72	8.48	1.47	32.00	2.40
North Dakota lignite.....	11.65	45.58	32.97	9.80	1.04	40.17	5.41
Illinois.....	12.40	32.18	42.82	12.60	1.30	30.12	2.08
Texas lignite (fine).....	19.78	62.50	6.57	11.15	1.03	35.42	27.08
Texas lignite (40-mesh duplicate).....	19.35	42.07	27.38	11.20	.....	35.72	6.35
Texas lignite (not air dried).....	30.45	44.40	15.42	9.73	.....	30.97	13.43
Massachusetts peat.....	13.25	49.80	16.21	20.74	.58	47.92	1.88

^a Two determinations upon the fine sample of Texas lignite made by heating for four minutes over a flame 5 centimeters high and then seven minutes over the full flame (25 cm.) gave 35.47 per cent volatile matter—almost an exact check upon the result obtained by the four-minute preliminary heating with a 10-centimeter flame regulated by holding burner in the hand.

With the exception of the anthracite and semianthracite samples, the results by the preliminary heating, as compared with those by the official method, all show a considerably less amount of volatile matter and a correspondingly greater amount of fixed carbon. In the case of the lignites, the greater volatile matter by the official method, as has been shown, is partly due to mechanical losses.

In order to see if mechanical losses might account for the differences on the bituminous coals, determinations for the ash after the determination of the volatile matter were made on one of the Pennsylvania samples. The average results for ash on the samples by the two methods are: Official method, 12.56; preliminary heating, 12.53. These results indicate no mechanical loss whatever, and in none of the samples except the lignites were visible solid carbon particles driven off in the form of sparks, and the differences must be ascribed to the different breaking down of the hydrocarbon compounds by the difference in heat treatment.

Comparisons of the results of volatile matter on a great number of samples differing from one another in moisture content indicate that the presence of loosely held moisture in the sample causes a higher volatile result. In order to obtain more definite data on this question, three samples low in moisture and representing widely different kinds of coal were selected for a series of determinations. The effect of loosely held moisture upon the determinations for volatile matter in each of these samples was determined by adding definite amounts of water to the sample after weighing out. The water was thoroughly mixed with the sample by means of a fine platinum wire and the volatile determination then made in the usual manner according to the official method. The first sample selected was a sample of Pennsylvania coal. The proximate analysis of the air-dried sample and the results for volatile matter determined in the presence of additional moisture are shown in the next table. Air-dried samples of Illinois coal and Arkansas lignite were treated in the same way, with the results also shown in the table.



minutes' preliminary heating over a low flame, determinations were made upon these samples with and without additional moisture, with the following results:

Determinations of volatile matter (percentages) after four minutes' preliminary heating, showing effect of loosely held moisture.

Fuel treated.	Volatile-matter determinations (by modified method) in the presence of stated amounts of added moisture.			
	No moisture added.	0.15 gram.	0.2 gram.	0.3 gram.
Pennsylvania coal.....	30.35			31.65
Illinois coal.....	34.85	36.10		
Arkansas lignite.....	36.90		37.40	

These results show that even with a gradual preliminary heating the presence of loosely held moisture increases the value of the volatile determinations, the difference in some of the samples being as great as the difference by the official method; from which it appears that the rapid application of heat sufficient to drive off this moisture results in a reaction between the water vapor and the carbon or hydrocarbons in the coal.

The results of the foregoing experiments and tests show that the value obtained for volatile matter in coal is affected to an important degree: (1) By the method of heating the sample, (2) by the fineness of pulverization, and (3) by the amount of loosely held moisture present. In bituminous coals these differences do not exceed 3 or 4 per cent, and appear to be entirely due to a different breaking up of the hydrocarbon compounds under the different conditions of heat treatment, fineness of sample, and amount of moisture present. In the case of lignites, where the difference may be as high as 25 per cent, this difference is largely due to the mechanical loss in the sample during the rapid expulsion of the volatile matter.

In the routine work of the laboratory in making the determinations of volatile matter the official method is at present used for ordinary bituminous coals, while lignites or other coals with more than 10 per cent moisture are heated for four minutes at a low temperature and then for seven minutes over the full flame of the Bunsen burner.



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CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 323.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports; Q, Fuels; R, Structural materials. This paper is the fifty-second in Series E, and the fourth in Series Q, the complete lists of which follow (PP=Professional Paper; B=Bulletin):

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- B 161. Earthquakes in California in 1898, by C. D. Perrine. 1899. 31 pp., 1 pl.
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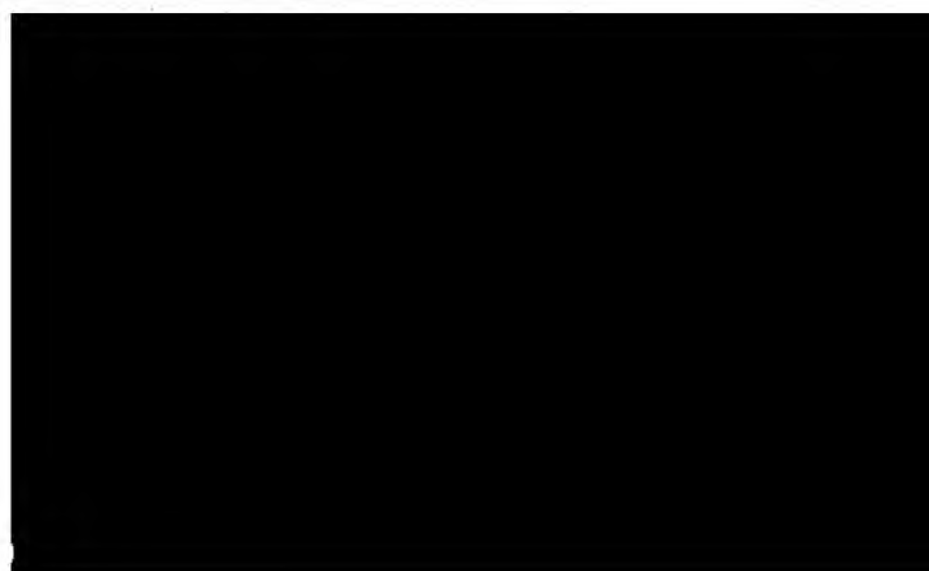
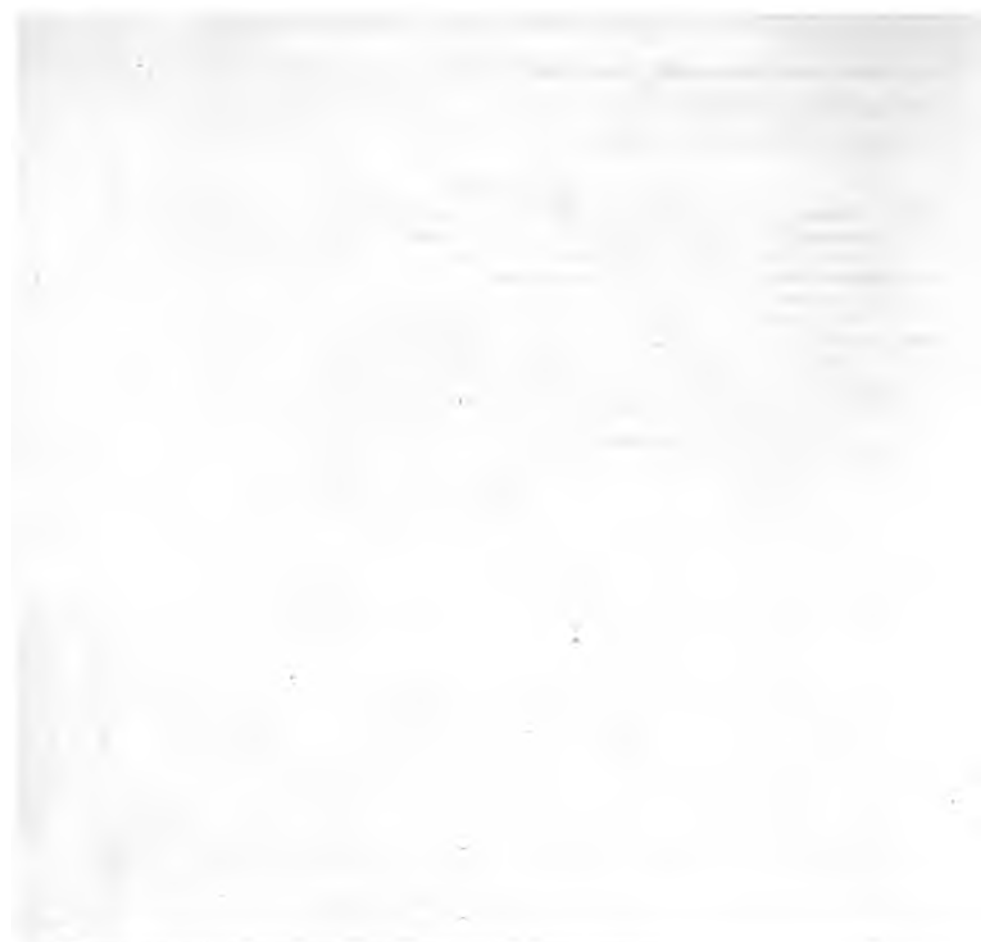
THE DIRECTOR,

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WASHINGTON, D. C.

SEPTEMBER, 1907.

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Bulletin No. 324

Series R, Structural Materials, 1

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

THE
SAN FRANCISCO EARTHQUAKE AND FIRE
OF
APRIL 18, 1906

AND THEIR EFFECTS ON STRUCTURES AND
STRUCTURAL MATERIALS

REPORTS BY

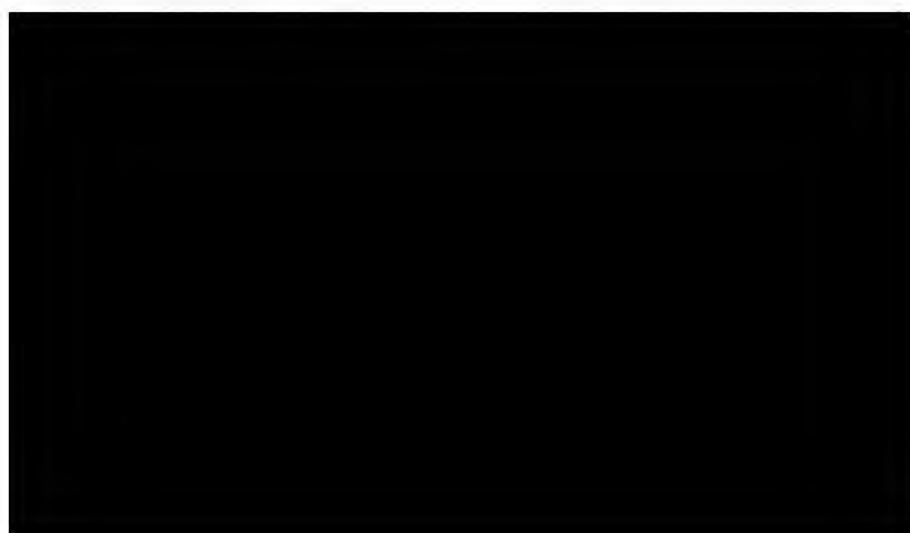
GROVE KARL GILBERT, RICHARD LEWIS HUMPHREY,
JOHN STEPHEN SEWELL, AND FRANK SOULÉ

WITH PREFACE BY

JOSEPH AUSTIN HOLMES
In Charge of Technologic Branch



WASHINGTON
GOVERNMENT PRINTING OFFICE



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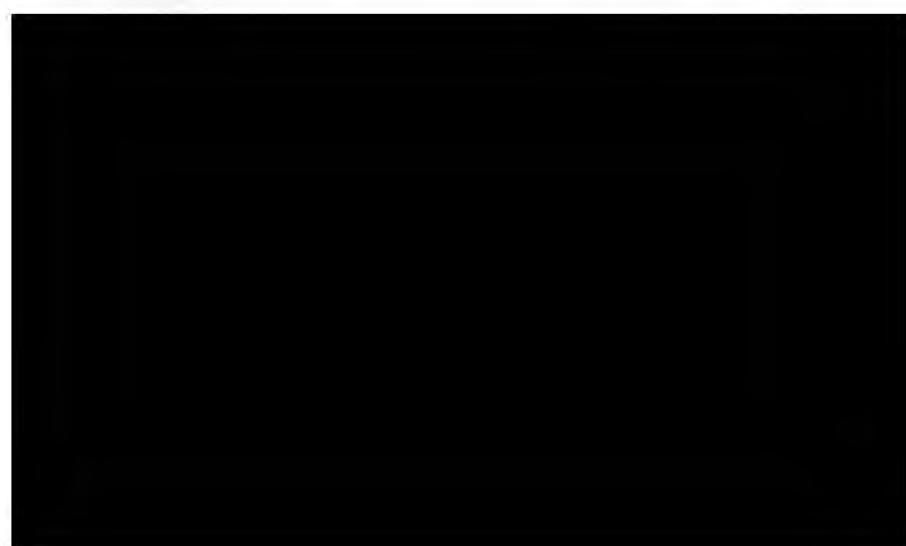
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PREFACE.

By JOSEPH A. HOLMES.

Immediately after the San Francisco earthquake and fire of April 18, 1906, it was decided to arrange for an investigation of their effects on buildings and materials of construction. Accordingly, on April 19 Richard L. Humphrey was sent to San Francisco for this purpose, as secretary of the National Advisory Board on Fuels and Structural Materials and representing the structural materials division of the United States Geological Survey. At the request of the President, Capt. John Stephen Sewell, Corps of Engineers, United States Army, was sent to San Francisco on a similar errand by the War Department under order of April 23, 1906. Frank Soulé, dean of the college of civil engineering of the University of California, was asked late in the fall of 1906 to prepare a report on the general earthquake and fire conditions. G. K. Gilbert, of the United States Geological Survey, also a member of the California earthquake investigation commission, who was near San Francisco at the time of the disaster, was asked to prepare a brief special report on the phenomena of the earthquake.

Mr. Gilbert has brought into his paper only the salient features and results of the earthquake, for the reason that the subject is being treated more fully in the report of the California earthquake investigation commission.

Mr. Humphrey, who during the last two years has had charge of the structural materials laboratories of the United States Geological Survey, has had many years' experience in the investigation of structural materials, especially with regard to their fire-resisting qualities.

Before going to San Francisco Captain Sewell had studied carefully the effects of fire on buildings and materials, especially as indicated by the results of the conflagration at Baltimore in 1904.

Professor Soulé has had the advantage not only of a large experience, but also of being thoroughly familiar with the conditions in San Francisco prior to the earthquake and fire, and of being on the ground during their occurrence. He has had subsequently every opportunity for studying, at first hand and in great detail, the effects of both the earthquake and the fire.

The investigations of these three engineers were conducted independently, and their reports have been prepared without collaboration. Under these circumstances there are necessarily some differences of opinion as to matters of detail, but as to the more important features the writers are in hearty accord. About four hundred illustrations were submitted with the original reports; many of these do not appear with the printed reports because their use would have involved duplication, but wherever a view given by one author was rejected because of its similarity to a view by another author showing the same engineering features, a reference to the accepted view has been inserted. The legend appended to each illustration indicates whether the original view was actually taken by the author or was procured from another source.

Persons interested in this subject are advised not only to read each of these papers, but also to consult a number of other important papers on this subject which have appeared in the different technical journals and the proceedings of technical societies during the last several months. (See list at end of bulletin, pp. 159-161.)

THE SAN FRANCISCO EARTHQUAKE AND FIRE OF APRIL 18, 1906, AND THEIR EFFECTS ON STRUCTURES AND STRUCTURAL MATERIALS.

By G. K. GILBERT, R. L. HUMPHREY, J. S. SEWELL, and FRANK SOULÉ.

THE EARTHQUAKE AS A NATURAL PHENOMENON.

By G. K. GILBERT.

INTRODUCTION.

The investigations to which the San Francisco earthquake has given rise are of two classes—the study of the natural phenomena constituting or associated with the earthquake, and the study of the relations of the San Francisco earthquake and future earthquakes to human activities.

The principal studies of the earthquake as a natural phenomenon are under the direction of the California earthquake investigation commission, which was appointed by the governor of the State three days after the occurrence of the shock. The human or economic aspects of the subject have been studied chiefly by engineers and architects, of whom a number have acted in private capacity, while others have acted as the representatives of governmental or private organizations. In many of the architectural studies the earthquake and fire have been considered together, as the destructive effects of these two sources of danger were closely associated in the San Francisco disaster.

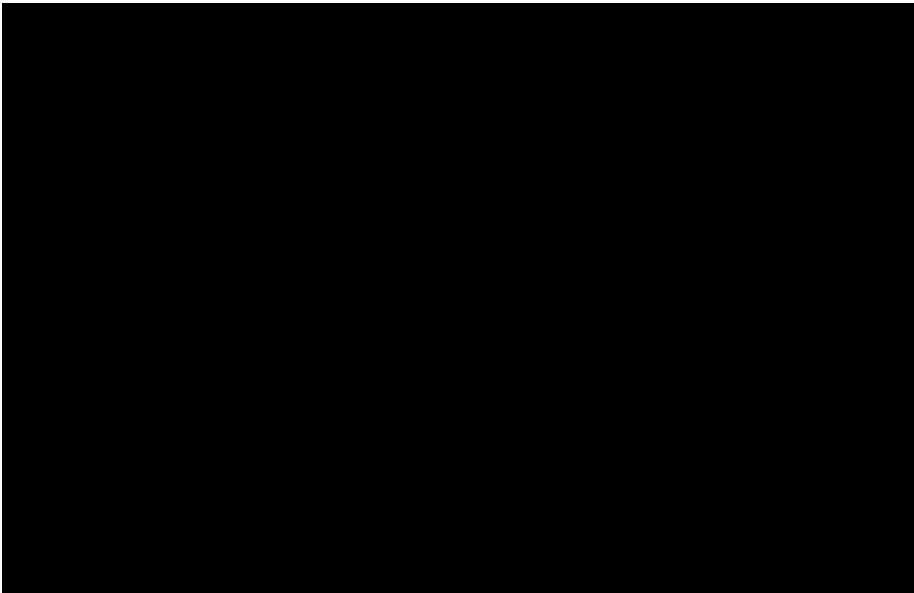
This volume is devoted to certain economic aspects of the subject, and the present chapter on natural phenomena of the earthquake selects those features which seem contributory to an understanding of the papers which follow. A fuller account of the earthquake may be found in the preliminary report of the State commission.

above referred to; and a monographic report is to be expected when the labors of this commission shall have been completed.^a

An earthquake is a jar occasioned by some violent rupture. Sometimes the rupture results from an explosion, but more commonly from the sudden breaking of rock under strain. The strain may be caused by the rising of lava in a volcano or by the forces that make mountain ranges and continents. The San Francisco earthquake of April 18, 1906, had its origin in a rupture associated with mountain-making forces. A rupture of this sort may be a mere pulling apart of the rocks so as to make a crack, but examples of that simple type are comparatively rare. The great majority of ruptures include not only the making of a crack but the relative movement or sliding of the rock masses on the two sides of the crack; that is to say, instead of a mere fracture there is a geologic fault. After a fault has been made its walls slowly become cemented or welded together; but for a long time it remains a plane of weakness, so that subsequent strains are apt to be relieved by renewed slipping on the same plane of rupture, and hundreds of earthquakes may thus originate in the same place.

A faulting may occur far beneath the surface and be known only through the resulting earthquake; but some of the quake-causing ruptures extend to the surface, and thus become visible. The New Madrid and Charleston earthquakes are examples of those having deep-seated origins; the shocks at Inyo and San Francisco, of those whose causative faults reached the surface of the ground.

The San Francisco earthquake had its origin, wholly or chiefly, in



fault trace and diminished with distance therefrom; but to this rule there are important exceptions, and it has been noted especially

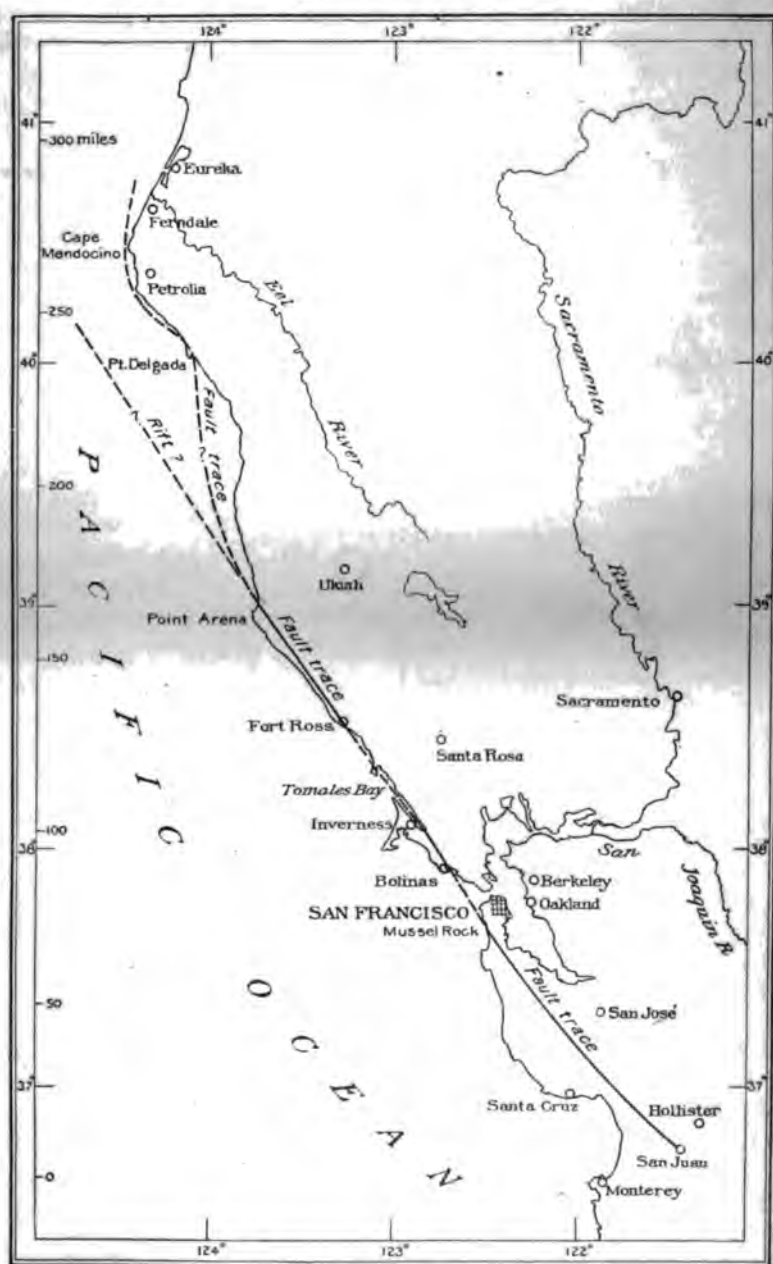


FIG. 1.—Map of the fault trace. Broken lines indicate alternative hypotheses as to its extension north of Point Arena.

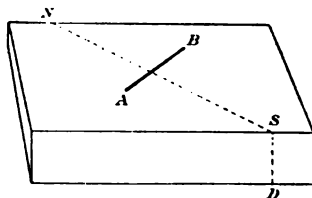
that an area of high intensity coincided approximately with the

fault. As the ridges of the neighboring Coast Range have the same northwesterly trend, it is thought probable that a subterranean slipping here occurred on a fault associated with the valley. In that case the geologic event causing the earthquake included coincident or nearly coincident yielding on more than one fault plane of the Coast Range system, and various other peculiarities in the distribution of intensity may be ascribed to local faulting.

The region of high intensity, to which most of the destruction was limited, is a belt 20 to 40 miles wide, extending from the mouth of Eel River at the northwest to Priest Valley at the southeast (fig. 1). This belt includes the surface expression of the principal fault—a feature distinctively known as the fault trace—a large number of cracks, and many local and superficial dislocations of soil and rock variously characterized as landslides and slumps.

THE FAULT TRACE.

The plane of the earthquake-causing fault, where it appears at the surface, is approximately vertical. The movement which took place along this plane was approximately horizontal.



THE EARTHQUAKE AS A NATURAL PHENOMENON.

rectangular block after the earthquake, its two parts dislocated by sliding horizontally along the fault plane, and the line AB made discontinuous by an offset.

To return, now, from the ideal to the actual, the sides and bottom of the earth block disappear. The depth to which the fault penetrates is indefinite and unknown, and so is the extent of the lands on either side affected by the displacement. For nearly 200 miles there is a fracture on the face of the land, and everything traversed by this fracture is dislocated, the part on the southwest side having apparently moved toward the northwest and the part on the northeast side having apparently moved toward the southeast. The total horizontal offset ranges in general from 2 to 16 feet, but at one place, affected by abnormal conditions, reaches 20 feet (Pl. I, A). The effect is also shown by a redwood tree (Pl. II), which was situated at a place where the displacement was slight. The average offset is 10 to 12 feet. Associated with the horizontal dislocation are vertical dislocations of minor and variable amount. This line of fracture, with the associated dislocation, is the surface expression of the fault which occurred on April 18, 1906. It is the visible trace of the fault across the surface of the land, and in the following pages will be called the "fault trace."

The fault trace itself is in some places inconspicuous, as in the field meadow represented in Pl. I, B, where one might readily walk across it without noticing that the ground had been disturbed. Its ordinary phase, however, includes a disruption of the ground suggestive of a huge furrow, consisting of a zone, between rough walls of earth, in which the ground is splintered and the fragments are dislocated and twisted. This phase is shown in Pl. III. In many places the fault trace sends branching cracks into bordering land, and locally its effect in dislocation is divided among parallel branches.

The views of the fault trace given in Pl. VII represent it at a point not far from the head of Tomales Bay, where it traverses a hillside having a general slope toward the southwest. In the upper view we look toward the northwest; in the lower, toward the south-southeast. The horizontal displacement is here about 16 feet, the ground at the left, in each view, having moved from us, and the

* In the case of an earthquake fault with important vertical displacement the surface expression is a small cliff or scarp, and to such a feature the name "fault scarp" has been given; but this name does not serve to characterize the feature produced by the horizontal displacement of April 18, 1906. In default of an appropriate and established name the geologists who first traced the feature made tentative use of "furrow" and "rift;" and the word rift was employed in the preliminary report of the California commission, in a popular article by the present writer, and probably in other places. The commission, however, in giving more deliberate attention to terminology, has determined to reserve the word rift for a meaning more in consonance with earlier geologic usage and to substitute "fault trace" for the surface expression of the fault. The present paper conforms to the nomenclature accepted by the commission.

ground at the right toward us. There is also a vertical displacement, the ground on the southwest side having been relatively lifted 1 or 2 feet, and the expression of the vertical change is exaggerated in the lower view by the relation of the horizontal change to the local slope of the hillside. There is nothing in the pictures to show the amount or even the direction of the horizontal displacement, but measurements were made at neighboring points where the fault trace intersects a road, a trail, and a small gully. The nature of the evidence as to displacement is illustrated by Pl. I, *B*, which shows a dislocated fence. The locality is on the farm of E. R. Strain, near the head of Bolinas Lagoon, and the camera was directed toward the northeast—at right angles to the trend of the fault trace. The main branch of the fault trace (which is here divided) crosses the foreground from left to right, touching the dissevered ends of the fence, but the shear is at this point so smooth that its surface trace is concealed by the grass. The fence, which before the earthquake was straight and continuous, was broken across and offset to the distance of $8\frac{1}{2}$ feet.

Between Point Arena and Fort Ross the course of the fault trace (see fig. 1, p. 3) is approximately parallel to the coast, passing to the east of all the coastal towns. From Fort Ross to the head of Tomales Bay it traverses the water, except at Bodega Bay and Preston Point, where for short distances it crosses the land. It again enters the water at Bolinas Lagoon, passing several miles outside the Golden Gate, and returning to the land at Mussel Rock, whence it follows a nearly direct course to San Juan. It does not touch any large town, but passes within a mile of Manchester, Plantation post-office, Fort



CRACKS.

All through the area of high intensity cracks were made, and these were specially numerous near the fault trace. The cracks were also more numerous in soft alluvium than in hard ground, but the number which deeply penetrated the bed rock was large. Perhaps this feature is better expressed by saying that the bed rock was generally and profoundly shattered, but without important dislocation except on the old fault plane. The wide prevalence of shattering is shown by the derangement of the underground circulation of water. In every farming district within the main earthquake belt persons familiar with the springs noted changes in the flow of water, ranging from moderate diminution or increase to complete stoppage or to the breaking out of new springs. In some places the derangements were temporary only, but more commonly a permanent change was reported.

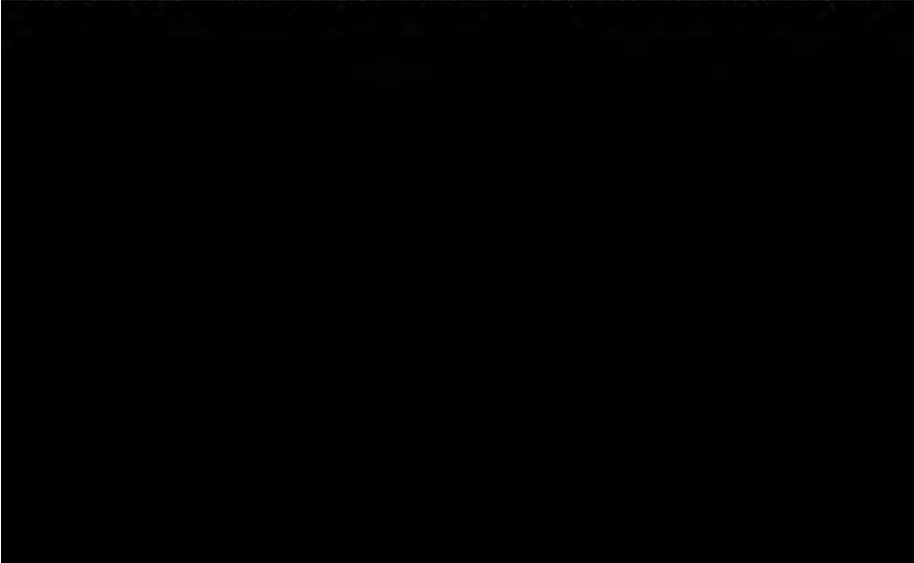
At the surface the cracks had great variety of expression. Some were barely perceptible as partings; others gaped so widely that one might look down them several yards. Some were mere pullings apart; others showed small differential movements of the nature of faulting. Some were solitary; others, especially those exhibiting faulting, were in groups. Some straggled and branched irregularly; others were nearly straight for hundreds of feet. Theoretically, some cracks were primary as regards the earthquake and others secondary; that is to say, some were caused directly by the preexistent stresses which produced the main fault and others were caused by the waves constituting the earthquake.

Pl. IV shows two types of secondary cracks. In *A* the cracks are crooked and without faulting. They traverse tidal mud near the head of Bolinas Lagoon and are near the main branch of the fault trace, which follows the base of the bluff seen at the right. The cracks seen in *B* are in Bolinas, within half a mile of the supposed position of the fault trace. The greater part of the village lies in a narrow valley dividing a plateau. The valley floor is of alluvium, the surface of which curves upward at the sides. As a result of the earthquake the alluvium settled somewhat toward the middle of the valley, thus forming along the bases of the hills a system of cracks associated with faulting.

DISLOCATIONS OF SURFACE MATERIAL.

The district most strongly affected by the earthquake is one in which landslips are normally of frequent occurrence. On many hill slopes were masses of earth or rock, the descent of which was sure to take place whenever conditions became favorable. The shaking of

the earth on the morning of April 18, 1906, supplied the lacking factor, and they were all loosened at once. In the simplest case, a poised rock toppled over and rolled down a slope. In other cases adhesion was overcome, with resultant sliding. In yet others strains occasioned by the sapping of cliffs were reinforced by kinetic strains and cohesion was overcome, with resultant fracture. Elsewhere an unconsolidated formation, even though in a dry condition, was made to flow by simple agitation. Hillside bogs and other bodies of wet earth lost coherence and flowed as mud. Slips of this character grade into those of wet alluvium or "made ground" resting upon gentle slopes—ground which under ordinary conditions flows or creeps at an almost imperceptible rate, but which by shaking was made to move several feet or yards in a few seconds. The filled districts of San Francisco afford several examples, and two of these are illustrated by Pls. V and VI, *B*. The view shown in Pl. V is northwestward on Ninth street, near Brannan. Before the earthquake the car tracks and curb line were straight and approximately level, and this condition was not disturbed on the relatively firm ground shown in the distance. In the nearer part of the view the street crosses a tract of made ground created by filling a valley tributary to a narrow tidal inlet called Mission Creek. The descent of this valley was southwestward, and the made ground flowed in that direction, carrying street and buildings with it. In taking the photograph reproduced in Pl. VI, *B*, the camera stood on ground made by the filling of Mission Lagoon, an expansion of Mission Creek, and was pointed northward, commanding a portion of Howard street. The made ground here flowed northeastward and the buckling of street-car tracks was



the vertical change as much as 2 feet. As the ascending movement can not be ascribed to gravity, it must be referred to the earthquake, even though the way in which the earth waves produced the effect is not evident. The locality is adjacent to the fault trace, the position of which is along the bottom of the bay, east of the shoal.

The illustrations may require a few words of explanation. The upper view of Pl. VII looks northward from the southwest shore of the bay. Tide being low, the newly formed shoal or mud bank is broadly exposed, but the receding tide has left a lane of water to mark the separation of the mud bank from the firmer ground that withstood the quaking. Immediately after the earthquake the mud was rigid, as in the tract shown in Pl. VIII, A; but before the view of Pl. VII, A, was taken (April 28, 1906) the surface had been largely smoothed by the action of wind waves. A single ridge which escaped that action appears at the left in the upper view of Pl. VII and in the foreground of the lower view.

A permanent disturbance of the ground also resulted in many instances from compacting. Just as sand or grain that has been poured into a measure can be made by shaking to settle down and occupy less space, so various loose formations, and especially artificial fillings, were shaken together by the earthquake and the ground surface lowered. In such compacting the particles making up the aggregate are readjusted so as to fit more closely together and the voids are reduced. In dry formations compacted by the earthquake the reduction of voids was opposed only by the elasticity of the contained air. In wet formations it encountered the effectual resistance of the contained water, and could be accomplished only by the extravasation of some of the water. Ordinarily it was impossible to measure the settling due to compacting, or even to determine its occurrence as a phenomenon independent of ground flow, but it was clearly seen in various localities in San Francisco where those parts of graded streets which retained their simple shapes and straight lines served as reference planes for neighboring parts that were disturbed. (Compare the distance and foreground of Pl. V. Another example of the effect on the filled-in land in this part of the city is shown in Pl. VI, A, a view of Dore street between Bryant and Brannan streets. The settling of the soft ground caused the street to drop at least 5 feet at this place.)

The only notable water waves generated by the shock were in Tomales Bay, where a group of waves estimated to be 6 or 8 feet high came to the northeast shore. The automatic tide gage at the Presidio showed a depression of about 4 inches, with subsequent oscillations of similar amount. Water was spilled from tanks, etc., and in at least one place was thrown from a pool out on the land.

MOTIONS CONSTITUTING THE EARTHQUAKE.

The earthquake occurred between 10 and 15 minutes after 5 o'clock a. m., standard time of the one hundred and twentieth meridian. As time was consumed in the propagation of the shocks, the moment of beginning at any place depended in part on the distance of the place from the zone in which the disturbance originated. As this zone was hundreds of miles in extent it is probable that the time of beginning was not the same at all points along it. For similar reasons the character and sequence of the motions constituting the earthquake were not the same at any two localities, and the differences in the vicinity of the zone of origin may have been very great. In and near San Francisco the principal part had a duration of about one minute; it was preceded by comparatively faint tremors for several seconds, and it was followed by minor tremors. During the stronger part the motion was chiefly in horizontal directions and oscillatory, but its rhythm was irregular in period and emphasis. On firm ground in the same region the range of motion is believed to have been more than 2 inches, but was not measured, there being no seismograph capable of recording it. On soft ground the range of oscillatory motion may have been several times greater, and it was also greater in the immediate vicinity of the fault trace.

The following paragraphs present my conception of the essential character of the motions constituting the earthquake in the region of its destructive intensity. In the endeavor to make a brief and clear statement the conception is expressed somewhat badly, with little reference to the various uncertainties of fact and theory by



At the initial tract a small movement sufficed to relieve the local strain, and the motion was then arrested by friction, but the movement was renewed by reaction from other tracts, and it alternately started and stopped till the accumulated stresses had spent themselves. There was a similar rhythmic sequence in other parts of the fault, the frequency of the alternations depending on local conditions; and the total movement of dislocation at each point was accomplished by a series of steps and not by a single leap.

The time consumed in these reactions was not infinitesimal. The rate of propagation of changes in strain was of the same order of magnitude as that of earthquake waves in general, and the rate of propagation of the initiation of movement on the old fault plane may have been somewhat slower because of the necessity of accumulating a certain amount of stress increment to overcome the adhesion. It is probable that the completion of the fault required more than one minute, and it may have required more than two minutes. It is even possible that the displacement had been completed at the initial point before it began at the most remote.

In the succession of slippings and stoppings at any point of the fault plane each separate slip communicated a jar or pulse to the surrounding rock, and this pulse was propagated in all directions. The earthquake at any locality in the neighborhood of the fault consisted of such pulses from different directions. The general distribution of intensity indicates that the pulses weakened in transmission somewhat rapidly, whence it may be inferred that the particular pulses constituting the dominant elements of the local earthquake were those from the nearer parts of the fault.

If this conception of the earthquake is correct, the rhythm observed in the region of high intensity was a phenomenon distinct from the rhythm of harmonic waves. It was essentially a frictional rhythm, dependent on the relation of certain rock strains and rock stresses to the resistances afforded by adhesion and sliding friction. It was irregular not only because the intervals of local starting and stopping were unequal, but because it was derived from a considerable area of the fault surface, in which the local rhythms were neither harmonious nor synchronous.

The compounding of unevenly spaced pulses from different points of the fault plane caused both reinforcement and interference, introducing a character analogous to beats in music, but without the regularity of musical beats. It also at times made oscillatory motions swifter in one direction than the other, so that reciprocative accelerations were not always symmetrically arranged. In less technical language, the motion was jerky and included abrupt phases that were almost blows. The compounding also introduced variety in the direction of motion, especially at the end when for a short time the

pulses from remoter parts of the zone of origin ceased to be overpowered by those from the nearest parts. The motion in that closing phase of the violent part of the earthquake has been compared by an observer to the motion of a vessel in a choppy sea; and I conceive that this comparison is the expression of a veritable analogy.

DISTRIBUTION OF INTENSITY.

When the isoseismal curves for this earthquake are drawn those for the higher intensities will show a remarkable elongation in the northwest-southeast direction. They will also show irregularities expressive of high intensity in the Santa Rosa Valley and other outlying areas. These features are related to the position and form of the zone or zones of origin. If drawn in detail they will show also the great influence of peculiarities of geologic formations. Detailed surveying has been attempted by the State commission only in San Francisco, partly because the results will there have the greatest practical value, and partly because the data are there most available. Notwithstanding the abundance of cracks, landslides, and broken trees in the region of high intensity, it is nevertheless true that natural structures in general are much less sensitive to earthquake violence than artificial structures, and for that reason grades of intensity are most easily mapped in cities.

The word "intensity" has various meanings as applied to earthquakes. As technically defined, it is the acceleration of the earth particle and is a quantity to be measured by the seismograph. But the field of instrumental observation is so limited that another defini-



made where the formations are alluvial. Doubtless many of the observations are fallacious, depending on a subjective illusion as to the direction of verticality, which arises from the horizontal movements of the observer's support; but some of them may also be objective. Not only is there a gradation in physical condition from dry earth through mud to water, but the shaking of a loose formation, whether wet or dry, overcomes the adhesion of particles and thereby imparts for the time being a mobility analogous to that of liquids. It is therefore conceivable that gravity waves, altogether analogous to those of water, may be produced by a violent earthquake on the surface of a loose formation. Certain ridges on soft ground caused by earthquakes in Japan are inferred by Omori and Kikuchi to represent such soil waves and to indicate a wave length (crest to crest) of 20 to 40 meters. The San Francisco earthquake produced a similar ridging on tidal mud in Tomales Bay, the average ridge interval being not more than half that of the Japanese examples. The Tomales Bay ridges are roughly parallel to the fault trace (which is close at hand), have about the same irregularity as wind waves, and originally ranged in height from 1 to 3 feet. They were observed chiefly, but not exclusively, on the body of mud already mentioned as having been shifted toward the southwest shore. The tract shown in Pl. VII lies so low as to be submerged much of the time, and the ridges had been so nearly obliterated when the views were taken that little remained besides an obscure indication of their ground plan; but an area nearer the head of the bay, and probably lying somewhat higher, not only seemed to have preserved its character when photographed (April 28; see Pl. VIII, A), but showed little change when visited nine months later.

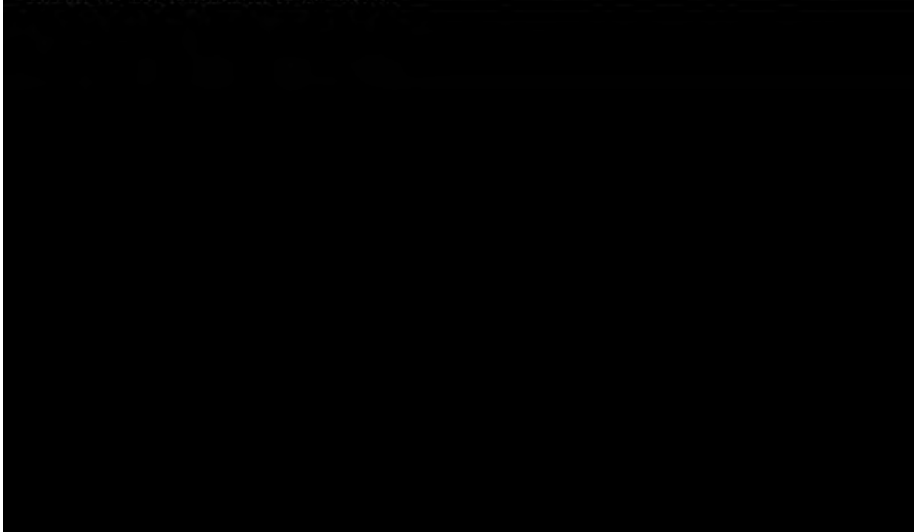
Notwithstanding the persistence of the ridges at the last-mentioned locality, there is no reason to question the statement that the whole mud plain had the smooth surface common to tidal flats until it was disturbed by the earthquake. Nor do I find any room for doubt either that the ridges originated as waves on the surface of the mud while it was rendered quasi liquid by violent agitation, or that they persisted because the mud promptly resumed its normal coherence when the agitation ceased. It is by no means equally clear that the arrested waves were true gravity waves rolling across the mud plain. Whatever their mechanism and history, they illustrate a mode of response of wet, unconsolidated material to powerful earth tremors, they suggest an explanation of certain wavelike ridges produced on areas of made ground in San Francisco, and they contribute to an understanding of the peculiar destructiveness of the earthquake in such areas.

THE EFFECTS OF THE EARTHQUAKE AND FIRE ON VARIOUS STRUCTURES AND STRUCTURAL MATERIALS.

By RICHARD L. HUMPHREY.

GENERAL DISCUSSION OF THE EARTHQUAKE CONDITIONS.

On the 18th of April, 1906, the whole civilized world stood aghast at the appalling destruction which visited the city of San Francisco and vicinity. Three weeks later, for the purpose of studying the effect of the earthquake and fire on structural materials, the writer began the investigation herein described, lasting six weeks and covering the entire affected territory. It would be impossible, however, to describe the extent of the damage adequately or comprehensively in a report of this character. When we consider the terrific destruction wrought in the surface of the earth by the first movement or "slip," which developed structural weaknesses, it is not surprising that this movement and the resulting vibrations should prove so fatal to the structures of man.



which successfully withstood the first test failed signally under the second, by reason of inadequate fireproofing. A very few withstood both tests successfully.

It is a generally accepted fact that no structure could have withstood the stresses produced by the movement of the earth at the "fault trace," along which the maximum intensity of disturbance was localized. The stresses produced by the vibrations at other points, however, could have been resisted with safety if proper design, first-class materials, and honest workmanship—constituting the whole secret of earthquake-resisting power—had been employed in the structures so located. In tall structures rigidity of construction, attained by adequate diagonal and portal bracing, is absolutely essential. In such buildings, owing to the inertia of the mass of the upper portion, the maximum bending moment exerted by the earthquake was applied at some point between the foundation and the top—generally just below the middle. While reenforced-concrete structures were few in the zone of seismic disturbances, these few stood the test by earthquake and fire in a highly satisfactory manner. Rigidity and stiffness and a high fire resistance are inherent qualities of concrete, and this material proved admirably suited to resist these extraordinary tests.

The destruction was greatest in structures built on filled ground, or on alluvial soils in the valleys of rivers, with foundations which did not go through to solid ground, the settling of the earth caused by the vibrations resulting in permanent displacement or distortion of such structures. At many places where great destruction took place, as at Palo Alto, San Jose, Salinas, Santa Rosa, etc., the structures were built on soft ground. In structures built on solid ground or rock formation the action was much less severe and was confined to shaking, producing a maximum oscillation in the upper portions of the structure.

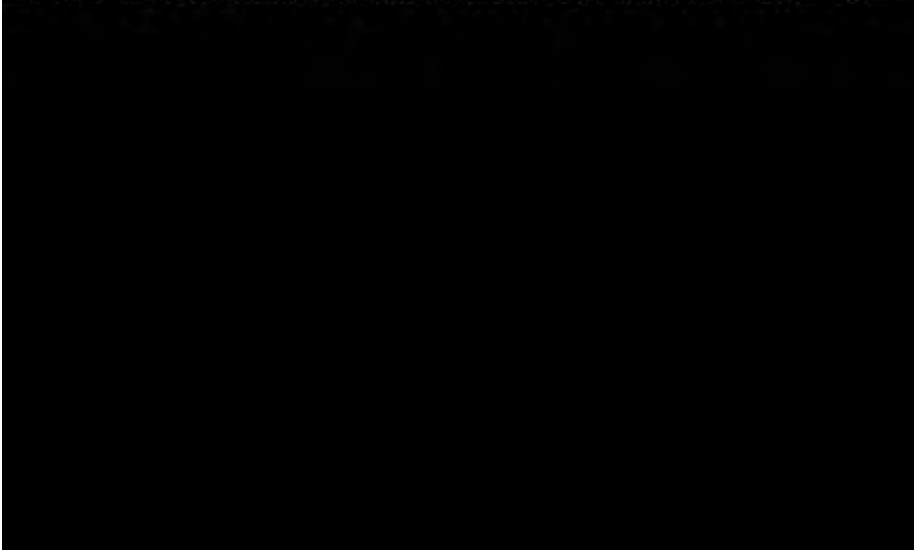
In order to understand properly the conditions under which such destruction as that caused by the earthquake could occur, one should study the geologic conditions prevalent just prior to the earthquake.

The history of the Pacific coast is replete with records of seismic disturbances, the entire region being in a condition of unstable equilibrium and cut by long rifts in the surface, called "faults," which have produced a series of long, narrow valleys. The forces which produce elevations and subsidence of the surface also produce stresses, which finally overcome the adhesion of the opposing rift walls, and earthquakes take place in the slipping of these walls, through a few inches or a few feet, in the effort to adjust the stresses. These earthquakes are of two classes—volcanic and tectonic. The former occur in regions of volcanic activity, are shallow in extent,

and affect comparatively small areas; the latter not only extend to a much greater depth, but also affect much greater areas. The region north and south of San Francisco is regarded as particularly susceptible to earthquakes of the latter type.

A. C. Lawson has traced several of the "faults" referred to, and about ten years prior to the San Francisco earthquake he indicated the location of the present fault trace south of the Golden Gate. His relief map of California serves to show the lines of known faults by the parallelism of the ridges and valleys. In following these valleys one finds evidence of faulting on every hand—the scars and markings on the earth and rocks, and the presence of little lakes or ponds without visible source of supply other than the watershed of the adjacent ridges. According to Lawson, the coast of California is rising, and the seismic disturbances whose record is found in the rocks have been produced by movements in the process of upheaval and subsidence, of folding and faulting, which are, perhaps, greater along the coast of California than in any other part of the world. Whatever may be the causes of these movements, it is apparent that the resultant stresses relieve themselves by producing these faults or rifts in the earth's surface.

The average Californian becomes accustomed to the earthquakes which produce "temblors" of sufficient intensity to rattle windows. Prior to the great earthquake of April 18, 1906, these temblors were of frequent occurrence, but occasioned no alarm and, indeed, scarcely excited a passing interest. Over two hundred earthquakes were recorded during the period from 1850 to 1886, being more prevalent in the vicinity of San Francisco Bay than elsewhere. The



passing under the ocean bed just west of the Golden Gate, reappearing on the land at Mussel Rock, and following the Pilarcitos and San Andreas pipe lines of the Spring Valley Water Company in a direct line to Hollister. The zone included San Francisco Bay, Russian River, and the Sonora, Santa Clara, and Salinas valleys. The first movement was along this zone in a southeasterly direction, and the vibrations set up on all sides produced a continuous twisting, rocking, wrenching movement that brought down chimneys, walls, towers, etc. In the opinion of the California earthquake investigation commission the slip commenced at the northwest end of the zone, and the force which occasioned the rupturing or shearing movement was a progressively decreasing one to the southeast end. As in the earthquake of 1868, the destruction was greatest in proportion to the nearness to the fault trace, and in parts built on soft or alluvial soil, or on "made ground." The earthquake as recorded by the seismographs showed a horizontal movement of about 3 inches and a vertical movement of about 1 inch, the velocity of propagation being about 2.1 miles per second. The wave movement was long and slow in hard soil and rock and comparatively short and incoherent in soft ground.

EFFECTS ON STRUCTURES OUTSIDE OF SAN FRANCISCO.

In considering in detail the damage wrought by the earthquake one must look for evidence in the country surrounding San Francisco, since the fire in that city obliterated most of the signs of the damage.

The greatest loss in the city of San Francisco was principally the result of the fire, which was rendered uncontrollable owing to the wrecking of the water-supply system by the earthquake. (See the maps of the city and vicinity, Pls. LVI and LVII.) An examination of the damage to the system at once suggests itself, especially as some of the main conduits are located on or near the fault line.

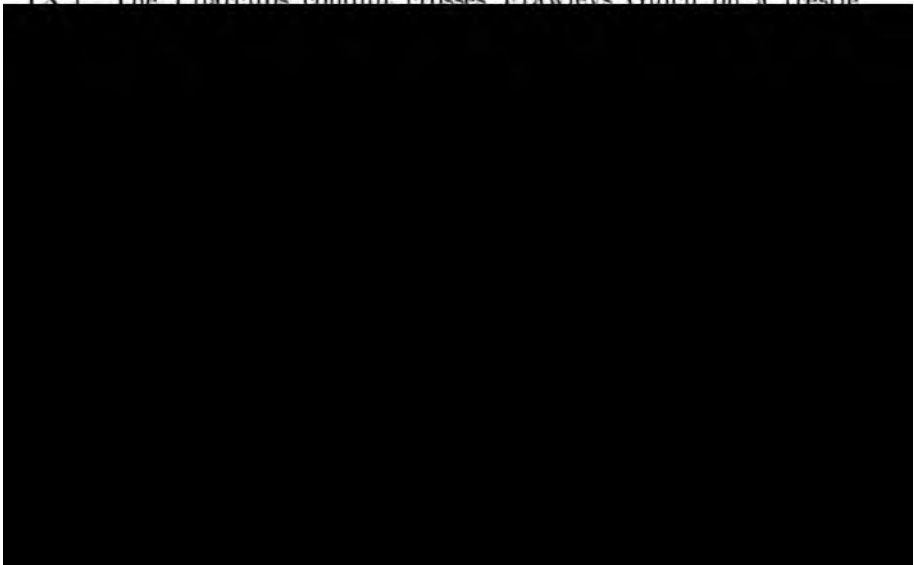
The city is supplied principally by gravity from three main distributing reservoirs, viz, University Mound, College Hill, and Lake Honda; there are also two supplementary sources—Alameda Creek, on the east side of the bay, and Lake Merced. The University Mound reservoir, having a capacity of 33,000,000 gallons, is supplied from Crystal Springs Lake through 17 miles of 44-inch wrought-iron pipe, carried for a considerable distance on trestles over the marshes. The College Hill reservoir has a capacity of 15,000,000 gallons and is supplied from San Andreas Lake through 14 miles of 44-inch, 37-inch, and 30-inch wrought-iron pipe. The Lake Honda reservoir, with a capacity of 31,000,000 gallons, is fed from Pilarcitos Lake through 16 miles of conduit, 1½ miles of which is wooden flume and the remainder cast-iron and wrought-iron pipe and brick tunnel. Of the two supplementary supplies, the water from Alameda Creek is car-

ried 27 miles, crossing San Francisco Bay through submarine pipes, and thence passing through the Crystal Springs conduit to the city; that from Lake Merced is pumped into the Pilarcitos conduit and thence to the city.

In company with Herman Schussler, chief engineer of the Spring Valley Water Company, the writer made a detailed examination of the principal conduits and reservoirs. On the San Bruno marsh the 44-inch line to the University Mound reservoir had been thrown off the trestle for a distance of 1,300 feet; and, while the pipe was readily repaired, the trestle had to be rebuilt, as many of the timbers had rotted. Near Baden the line had been telescoped 42 inches, shearing off an 8-inch gate valve. The reservoir itself was undamaged, yet its three days' supply was rendered useless by the breaks in the cast-iron distributing mains.

The only damage done to the conduit between San Andreas Lake and the College Hill reservoir was at Baden, where the slip joint had been broken, tearing out the four cast-iron lugs—an effect indicating a force of at least 2,000,000 pounds.

The principal breaks in the Pilarcitos conduit, which was so badly damaged that the company decided to abandon it, were examined. This conduit had been located for convenience in one of the long, narrow valleys, and therefore on the line of an old fault. It is evident that it would be futile to attempt to build this conduit strong enough to withstand a slip on the fault line. The breaks in this 30-inch wrought-iron pipe ranged from 30 inches to 6 feet in length. At other points it was telescoped and twisted beyond repair. (See Pl. IX.) The Pilarcitos conduit crosses Crawleys Gulch on a trestle



point for 50 feet. A brick conduit used for waste purposes extends across the fault. All the four rings, of hard-burned brick, are laid in first-class Portland-cement mortar, making a first-class piece of work in every way. This conduit, which is 9 feet 6 inches in diameter, was crushed together at the crossing.

The Searsville dam, a structure similar to the San Andreas earth dam, 1 mile east of the fault line and parallel to it, was also found to be uninjured.

Very little damage was done to the pumping stations, and the steel standpipes of this company were not injured. The Lake Honda reservoir was slightly damaged by a crack in its concrete lining. No damage was done to the Alameda Creek supply, except to the connection at the Belmont pumping station.

The concrete dam near San Mateo, at the lower end of Crystal Springs Lake, parallel to the fault line and a few hundred feet east of it, was undamaged. This dam, a view of which is given in Pl. XI, *B*, is built of large blocks of concrete, thoroughly keyed together and molded in place, each block containing between 200 and 300 cubic feet. The dam is 680 feet long, with a present height of 146 feet. When completed it will be 170 feet high, 176 feet thick at the base, and 25 feet thick at the top. It is arched upstream to a radius of 637 feet.

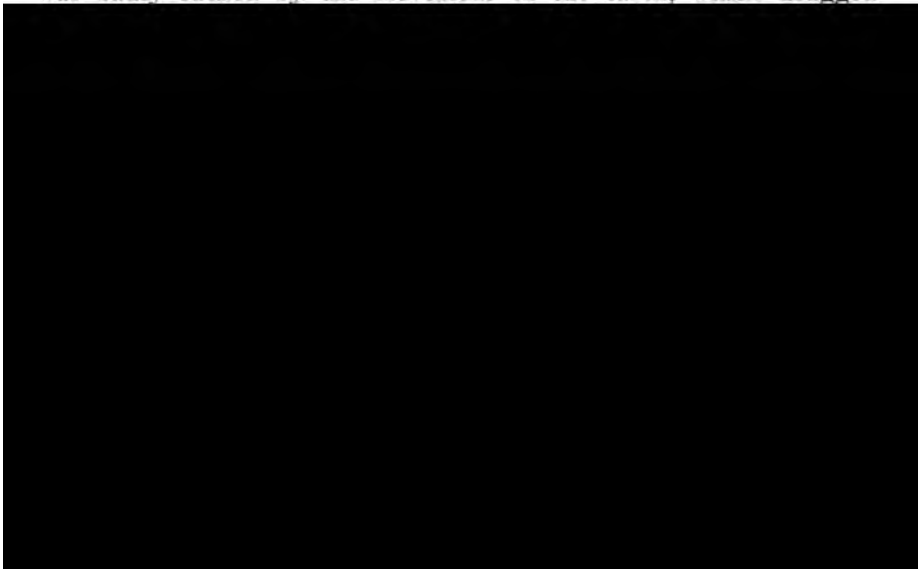
The clay-core earth dam of the upper Crystal Springs Lake lies across the fault line at nearly right angles. This dam is now maintained as a county causeway, equalizing pipes having been placed through it. At the time of the earthquake the water was at the same height on each side, and the absence of any "head" made it impossible to tell the extent of the damage. The dam moved about 6 feet, however, this fact being shown clearly by an offset of that amount in the fence which runs across it. The roadway over the dam also shows the same offset, although not so clearly.

The water supply of San Francisco, as compared with that of other cities, was fairly good and had a rated capacity of 36,000,000 gallons per day. The failure to control the fire by reason of the crippling of the water supply was not due to the failure of the system outside of the city, but to the breaks in the distributing mains within the city, which rendered unavailable about 80,000,000 gallons of water stored within the city limits. These breaks occurred (see the map, Pl. LVI) wherever the pipes passed through soft or made ground. No breaks occurred where the cast-iron pipe was laid in solid ground or rock. It is evident that in earthquake countries water-supply pipes, at least, should be so laid as to avoid the action of slips, settling, and ground movements of all kinds. The pipe lines should also be arranged with gates and by-passes, making it possible to cut

out any portion of the system which may become crippled. There should also be some means of preventing the loss of water which is occasioned by breaks in the house service pipes.

While one of the main conduits was badly damaged wherever it crossed the fault, this damage was no greater than that done to any other structure that was situated at the fault line. Structures so located were torn apart, the gap in the case of a fence (Pl. I, *B*) or road (Pl. I, *A*) being from 6 to 20 feet, according to local conditions. In the country around Fort Ross there were many trees located on the fault that showed the effect of the slip. Great redwood and pine trees were either twisted out of normal position or split (Pl. II) from the roots up for distances of 35 feet or more, even when perfectly sound. This splitting action was due to the earth on the west of the line of faulting moving the roots on that side, a motion which tended to pull the tree apart. Where the tree had some defect or was unsound (as from dry rot) the action was even more marked and the destruction much greater. Redwood trees grow to great heights and are perfectly straight, and to find one out of plumb is very unusual.

Another interesting example of the effect of the slip along the line of the fault is afforded by the Southern Pacific Railroad bridge over Pajaro River near Chittenden station. This bridge crosses the fault obliquely at a very acute angle—about 10° . It consists of two girder shore spans of 50 feet each and three Pratt truss river spans of about 100 feet each. The piers and abutments are built of concrete, with granite coping and bridge seats (Pl. XI, *A*). The bridge was badly racked by the movement of the earth, which dragged



The Saratoga reservoir of the San Jose Water Company lies in a saddle of the Santa Cruz Mountains between Saratoga and Los Gatos, and the fault line crosses it at right angles, the cracks extending through the body of the dam. The reservoir was full at the time, but there was no apparent loss of head.

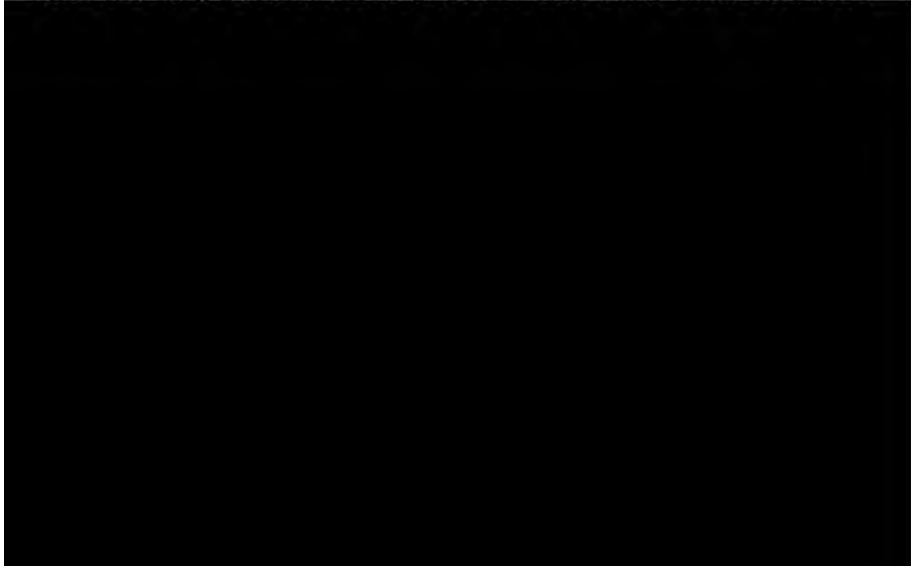
As already stated, in the country bordering the line of faulting the damage done was greater in soft or alluvial soil or made ground. Most wooden water tanks on low supports were wrecked, not only in the vicinity of the fault line but throughout the affected zone, the failure being due to a lack of lateral bracing of the trestle support. Chimneys generally collapsed, the cause being the unequal movement of the inelastic brickwork and the usually elastic frame structure surrounding it. Wooden buildings on good foundations stood well, the chief damage being to the chimneys and plastering. The alluvial or soft soil forming the banks of rivers generally moved toward the river under the earthquake vibrations, the settling of the ground being most marked (Pl. VIII, *B*). The country in the vicinity of Salinas River presented interesting features of this character. The county road crosses the river near Salinas on a wooden bridge, and the slipping of the banks carried the south abutment 6 feet toward the river. The ground was badly cracked and there were a number of slips in the neighborhood. The road leading to Spreckels's sugar mill, 4 miles south of Salinas, was also greatly damaged by the slips. Spreckels's sugar mill (Pl. XII, *A*) is located on soft alluvium. The main building, which is 500 feet long, is said to be the largest sugar mill in the world. The vibrations of the earth jarred the brickwork loose at the end of the building, which buckled in the middle, where there were no floors above the second floor. The damage to other buildings was also extensive. The town of Salinas itself was severely shaken. The high-school building and some of the buildings on the main street were damaged, chimneys were thrown down, and a water tank of the Southern Pacific Railroad, supported on a steel trestle near the station, collapsed.

Along the Bay of Monterey the whole shore slipped about 12 feet into the bay, the movement buckling the rails on a railroad trestle and the cars dropping about 5 feet. A frame house and surroundings moved 12 feet, still maintaining their relative positions. In Monterey the principal damage was in the loss of chimneys and cracking of plaster.

At San Jose, located on the soft alluvium of the Santa Clara Valley, the destruction was extensive. The post-office, a very substantial building, lost its tower, which was laid up in lime mortar, and was deficient in lateral bracing. The walls were of brick with a 4-inch or 6-inch stone veneer, and there was a wooden-framed slate-roofed tower. The collapse of the tower damaged the pavement and

to some extent the building itself. The damage to the hall of records, along the end walls, was due entirely to defective construction. The Hall of Justice (Pl. XII, *B*), which was completed in 1905, had the wall along the cornice line thrown down. The reenforced-concrete roof contributed no little to the support of the walls of the building, and had the stonework been less heavy and of better quality the damage probably would not have been so extensive. The high school (Pl. XIII, *B*), a flimsy structure of brick with wooden frame, was so badly wrecked that it had to be torn down as a matter of safety. The destruction of the buildings along First street, the principal business thoroughfare, was also extensive. Lime mortar, flimsy framing, poor design, and lack of tie between floor and roof members and walls were the causes of these failures.

Perhaps the worst example of poor design, bad workmanship, and poor materials in the earthquake territory, except in the city of San Francisco, is the insane asylum at Agnew, about 6 miles northwest of San Jose, consisting of a main building surrounded by a number of others—all flimsily constructed brick structures with timber frames. The construction of these buildings, with their thin walls (in many places devoid of mortar) and light, insufficient wooden framing, indicates a criminal negligence that is appalling. One hundred and seventeen patients and attendants lost their lives, principally from the fall of the central tower of the main building. The brick stack of the power plant and the towers of surrounding buildings collapsed. In the farmyard near by is a water tank supported on a wooden trestle. This tank moved about 10 inches, while less than a stone's throw away are four water tanks supported



6-inch face of stone, poorly bedded, containing a large percentage of spalls, the lime mortar being of good quality. The construction is fairly common in other parts of the country. The roof trusses were not anchored to the walls, but to a great extent were butted against the walls; the floor joists rested in the walls and were not tied. Under the vibrations the walls were pushed out of plumb and, having no proper connection with the floor and roof members, collapsed.

The gymnasium and library presented interesting features. The dome of the library was supported by a skeleton of steel, and although the surrounding walls collapsed, this dome was not damaged (Pl. XV, A). The gymnasium dome rested on intermediate brick walls, which collapsed with the dome (Pl. XV, B).

The boys' dormitory (Encina Hall) was built of stone, and was one of the buildings erected by Senator Stanford. The chimneys of this structure collapsed and crashed through the roof and floors, killing one student and injuring several others. The walls themselves were but slightly cracked. The girls' dormitory (Roble Hall) had walls of reenforced concrete with wooden floors. The chimneys on this structure also collapsed, but no other damage was done, the walls being left intact, without any cracks.

The memorial arch (Pl. XVI) was a poorly designed structure, 100 feet high, with stone-veneered walls. The structure above the arch ring was hollow, and an attempt had been made to stiffen it by the use of a number of I beams. These beams were not tied to the stonework, but simply rested upon it, and under the action of the earthquake they became battering rams and helped to accomplish the destruction of the arch. The arch as first designed was 75 feet high, and it will be noted that the earthquake reduced it to the height originally intended (Pl. XVI, B).

The memorial chapel, one of the most beautiful buildings in this country, was almost completely wrecked (Pl. XVII, B) by the collapse of the tower. A platform of steel beams had been placed under the clock as a precaution against the chance falling of the pendulum, and this platform saved the clock. The damage done to the mosaic work and the interior decoration is probably irreparable.

The chemical laboratory was damaged by falling chimneys, and gable walls were pushed out and suffered considerable damage by the collapse of the assay stack. The plastering was also badly cracked. Great damage was also wrought in the power plant of the mechanical engineering department by the falling of the stack.

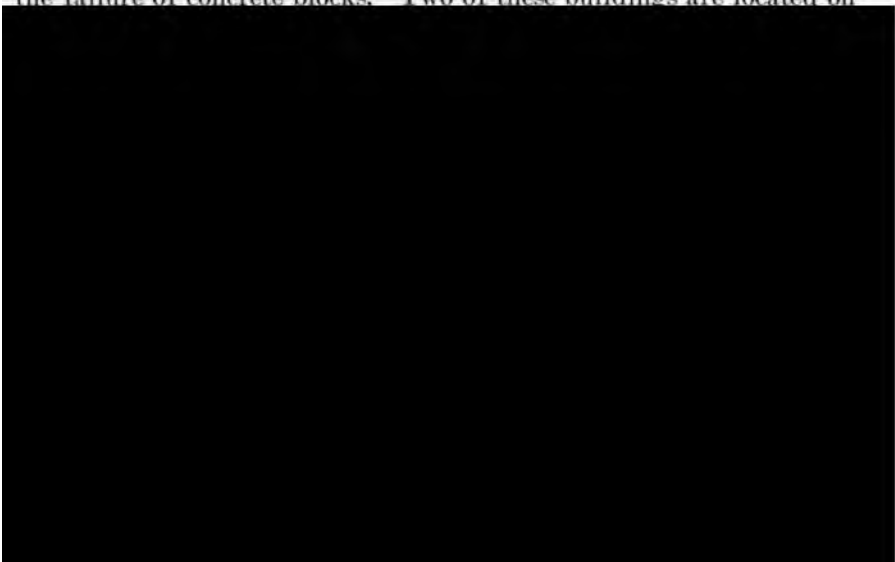
The quadrangle, or main academic portion of the university, was built by day labor and was a fair piece of work. The cloister (Pl. XVIII, B) suffered considerably, the bases and caps of the columns being spalled and chipped, indicating that they must have been sub-
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a number of them the arch stones had dropped partly out of place. The department of geology (Pl. XVIII, A), the newly completed end of the quadrangle, suffered the greatest damage; many of the walls will have to be rebuilt, having been either cracked very badly or destroyed entirely. The plastering was badly cracked and showed the outline of each sheet of metal lath. Where reenforced concrete was used the ceilings were free from cracks.

The most interesting building is the museum (Pl. XIV, A), which consists of a central pavilion of reenforced concrete and wings of brick plastered with cement mortar. The columns of the central pavilion are solid concrete, having been cast in place. This building had wooden floors. The wings were wrecked by the earthquake, but the central pavilion escaped injury, although its contents were more or less damaged, principally by being shaken from their positions.

Although the destruction at Stanford University was very great, the character of construction was fair and did not suffer by comparison with that used in other parts of the country. The excellent qualities of reenforced concrete and its ability to withstand earthquake shock were strongly demonstrated.

The town of Palo Alto suffered considerably from the earthquake. Chimneys were generally thrown down. A number of buildings were wholly or partly wrecked, the causes of the failures being similar to those in other sections, consisting largely of defects in design, lack of adequate bracing, poor mortar, and bad workmanship. Three concrete-block buildings were either wholly or partly destroyed and have especial interest, since they have been cited as evidence of the failure of concrete blocks. Two of these buildings are located on



held the walls and roof together and made them move as a unit. The cornice was rebuilt before the view was taken. While buildings of brick and stone collapsed all around this one, it received practically no damage and demonstrated that structures that will successfully withstand earthquake shock can be built of concrete blocks. The other buildings at Santa Rosa did not present any interesting features, as they were mostly defective in design and workmanship and the material was generally poor. The city hall, the court-house (Pl. XIV, *B*), the Masonic Temple, the Keegan-Brush Building, and the St. Rose Hotel were all completely wrecked, and added their testimony against poor mortar in brickwork, light wooden frames, and insufficient bracing.

Towns like Berkeley and Oakland did not suffer as greatly from the earthquake as many neighboring towns, the reason lying in the fact that these towns are built on solid ground or on rock. In Berkeley, while chimneys were shaken down, there was no extensive earthquake damage. The Greek Theater, a massive structure of concrete, was uninjured. In Oakland, however, greater destruction occurred. Just outside of Oakland is located the Mills College for Girls. The science building had brick walls plastered with cement mortar, and was considerably damaged by the shaking it received and the falling chimneys. The building had wooden floors and was considerably racked, the walls being pushed out slightly. Within a few feet is the bell tower (Pl. XX, *B*), a reenforced-concrete structure 80 feet high with walls 4 inches thick, which was not damaged in the slightest degree.

CONDITIONS IN SAN FRANCISCO.

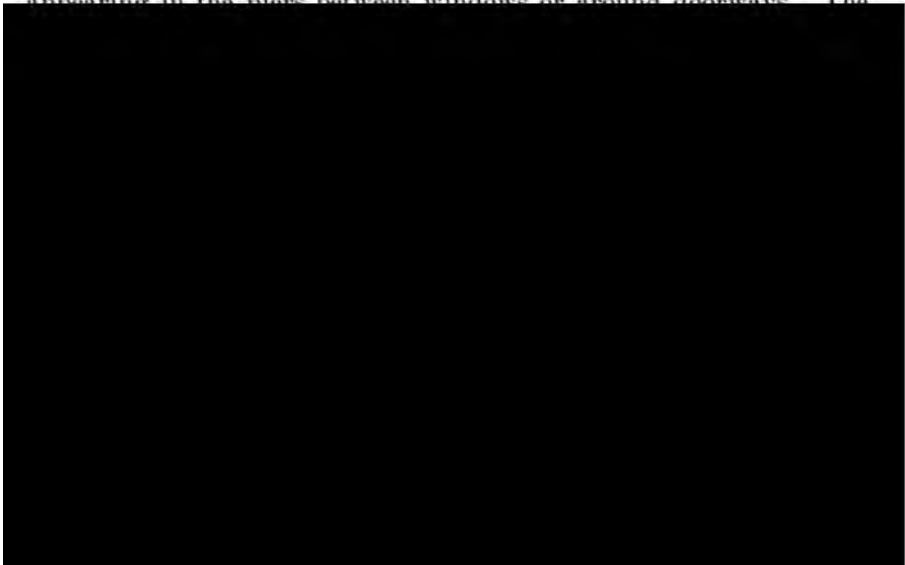
GENERAL EARTHQUAKE CONDITIONS AND EFFECTS.

Within the city of San Francisco (see the map, Pl. LVI) the havoc wrought by the earthquake depended on the character of the construction and its foundation. Bordering San Francisco Bay, from Telegraph Hill to Mission Creek, the land consists of mud flats, which have been gradually filled in, and on this land many large commercial buildings had been erected, among others being the Union Ferry building, the post-office, the mint, and the custom-house. Adjoining this filled land was comparatively level ground composed of sand and clay formed by the wearing away of the hillsides and by the incoming sand from the seacoast—a fringe of soil on which were located many of the principal buildings. From Telegraph Hill southwestward along Russian Hill to Sutro Heights runs a ridge of rocky hills composed of indurated clay shale, with serpentine and

The signs of destruction wrought by the earthquake in the city of San Francisco were more or less obscured or in many places entirely obliterated by the fire. The best evidence of the earthquake can therefore be obtained outside the burned district, and the following notes cover the most important examples of damage due to the earthquake alone.

As in districts outside of San Francisco, the greatest damage was done to those structures having insufficient foundations built on soft alluvium or filled ground. The settling of the ground in the mud flats along San Francisco Bay and of the filled ground in old water courses was accompanied with great destruction. It was in such ground that the greatest number of breaks occurred in the cast-iron gas and water mains and the sewers. The breaks in the sewers were not so evident as those in the gas and water mains, for the reason that the latter were under pressure and breaks in them resulted in breaks in the streets themselves. The most noticeable destruction resulting from the settling of soft or filled ground occurred in Howard and Shotwell streets between Seventeenth and Eighteenth streets, Bryant street between Ninth and Tenth streets, Dore street between Bryant and Brannan streets (Pl. VI, A), and at the corner of Seventh and Mission streets. The settling was greatest in Howard, Dore, and Bryant streets, being in Dore street at least 5 feet.

On solid ground the earthquake had a rocking effect which produced X cracks (Pl. XXII, A) in the brick or stone walls of those buildings which were deficient in diagonal bracing. This was especially true in the upper stories of tall buildings, the cracks generally appearing in the piers between windows or around doorways. The



and the poor quality of the mortar used in the brickwork. Again, in the Hahnemann Medical College, on California street near Maple street, the destruction of the end walls was the result of bad design, the roof trusses butting against the walls and the floor timbers resting upon the walls without adequate tie. The poor quality of the mortar permitted a ready disintegration of the brick-veneered walls, although some band iron had been used for the purpose of strengthening them. The Cathedral of St. Dominic, with its high, unbraced brick walls and its peculiar wood-sheathed spires, also proved a victim of poor design and workmanship; the sheathing on the spires was shaken off and the collapse of the walls resulted in extensive damage to the interior.

In interesting contradistinction to these failures was the Sailors' Home, erected in 1858 for use as a marine hospital and condemned as unsafe after the earthquake of 1868. Its heavy brick walls, reenforced with band iron and further stiffened by cross walls thoroughly bonded, are in excellent condition. The building rests upon rock and the framing is excellent; the rafters are fastened to a wall plate which ties the walls, causing the structure to move as a unit. The only cracks occurred where partition walls which had been added were shaken loose from the main walls and around the archways leading to the main stairway on the second and third floors, where no extra stiffening of the walls had been provided. The building in all other respects suffered no damage, there being no new cracks apparent in the exterior walls.

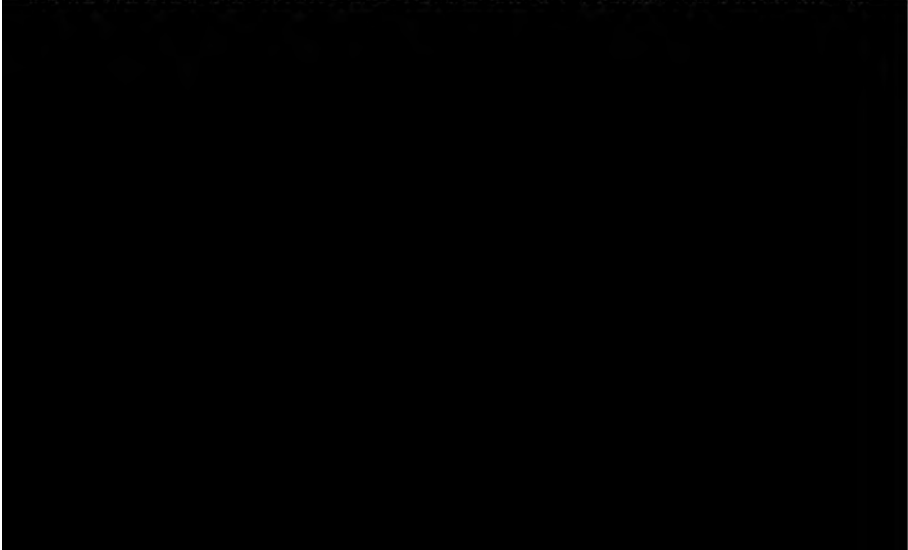
The old red-tiled Spanish Mission Dolores (Pl. XXIII, *B*), built in 1777, with its adobe walls and wooden frame, was not injured, while its more modern successor was greatly damaged. The complete collapse of the tower of the new Mission Dolores was not brought about directly by the earthquake, but the damage was such that the tower had to be taken down, as shown in Pl. XXIII, *B*.

The group of buildings comprising the plant of the San Francisco Gas and Electric Light Company, built on the soft ground along San Francisco Bay just west of Fort Mason, was badly shaken, and none of the buildings escaped damage. The collapse of the stack wrecked the light slate-covered iron roof of the power house and started the fire that destroyed the roof of the boiler house. The ground settled very considerably under the vibrations of the earthquake, and further destruction was caused by the unequal settling of the building. The main shock appeared to come from the north, and the north walls received the greatest damage. The end wall of the retort house was pushed out 1 foot at the center, but was saved from collapse by the tie-rods which held it to the roof truss. The walls were cracked at the northwest and northeast corners. The and gas-tar holder houses were wr

roof trusses collapsing. Nearly every wall was moved slightly, but the brickwork was generally very good, and apparently had cement in it. The exhaust house had three intermediate walls, 18 inches thick at the top. The north wall and the next one fell into the building, the side walls being pushed out 6 inches. The building had wooden roof trusses and the north truss cracked at the center mortise. The floor settled badly around the condensers. The gas holder collapsed from the sudden release of the gas due to a break in the mains. The trestle pier extending into the bay also collapsed.

Most of the structures built on piles along the bay suffered considerable damage, especially the frame sheds on the wharves. The Union Ferry Building (Pl. XLVI, A), the terminus for all the ferries plying on the bay, is built on piles. It was more seriously damaged by the earthquake than would appear at first sight, and barely escaped the fire also. It is of interest to consider in some detail the behavior of this structure under the action of the earthquake. The ten-story tower was so seriously damaged as to require the removal of the masonry walls, and will probably have to be rebuilt. This tower consists of a steel frame which was inclosed with heavy sandstone walls backed with brick for several of the lower stories, and with sheet metal above. The floors above the masonry part were of stone concrete reenforced with expanded metal between I beams. The brick walls were badly shattered, and a large section was thrown out just below the clock on the west front, while on the east front a large mass fell through the skylight onto the upper story of the main building. There were but few cracks in the north and south walls. The steel

time ball staff was badly bent, indicating a considerable movement of



two of the rivets holding the clip support for the west girder. The floor of the main building consisted of groined arches of stone concrete springing from concrete piers supported by cluster piles. The self-supporting walls of sandstone backed with brick were more or less shaken, and the piers of the driveways were badly cracked; the floors were of stone concrete reenforced with expanded metal between I beams and supported by cast-iron columns. The concrete in this building appeared to be undamaged.

Most of the entrances to the cemeteries were wholly or partially wrecked, and the burial vaults and gravestones were all more or less disarranged. It has been estimated that perhaps 60 per cent of the monuments, vaults, etc., in cemeteries were overturned or moved.

In Golden Gate Park nearly every stone or brick structure was damaged. The emergency hospital, a single-story brick and stone-veneered building, lost its gable walls and was damaged in the same manner as other structures having improperly bonded walls laid in lime mortar, and deficient in proper ties between the masonry and the other structural parts. The gable walls of the restaurant in the children's playground were thrown down by the earthquake, but the greatest damage resulted in the settling of the foundation of one of the columns, which caused the collapse of the structure. The music stand, a stone-veneer brick-backed structure, was racked and shaken. Part of the pediment was shaken loose, and many of the columns were spalled and moved. Some of the walls of the museum were thrown down, and its contents were more or less damaged.

All the monuments were damaged. The Francis Scott Key monument (Pl. XX, *A*) was racked so badly that the arch stones were shaken loose, the columns spalled at cap and base, and the monument as a whole moved on its foundations.

The most interesting structure in Golden Gate Park is the cyclorama (Pl. XXIII, *A*), on the top of Strawberry Hill, built about fifteen years ago. The top of the hill had been leveled off in order to form a foundation. The cyclorama consisted of circular walls of reinforced concrete, the aggregate of which was a hard shale crushed to concrete size. This material was very inferior and yielded a poor concrete. The reddish-brown effect was obtained by means of a veneer ($1\frac{1}{2}$ to 4 inches thick) of a concrete consisting of crushed brick, sand, and cement. The reinforcement in the base consisted of four $\frac{7}{8}$ -inch cables of thirty strands each. The reinforcement of the columns consisted of $\frac{3}{4}$ -inch twisted bars and $\frac{1}{2}$ -inch stirrups. The entrance, with its very heavy, massive top, should have been of hollow-construction reinforced concrete. The settling of the foundation or fill under the vibration of the earthquake caused the structure to collapse. The slip (Pl. XXII, *B*) occurred principally on the north-
ie movemen

the base was about 11 inches wide, with a half-inch horizontal crack leading from it along the reenforcement. The floor is in good condition, except the pavement, which broke into blocks, most of the planes of fracture coinciding with the actual joints between the different sections. Under the circumstances—the undermining of the foundation by the slip as described—the structure developed remarkable strength. No brick or stone structure could have stood the shock so well. The rustic railing around the outside of the walk (Pl. XXII, *B*), which was of wrought-iron pipe covered with wire mesh and plastered with Portland-cement mortar, was distorted by the slip, but otherwise uninjured.

At the bottom of Strawberry Hill is a bridge crossing over Stow Lake. This bridge is made of concrete, and showed no signs of cracking, although the banks of the lake slipped into the water.

BEHAVIOR OF INDIVIDUAL STRUCTURES.

GENERAL STATEMENT.

The numerous fires that broke out all over the city were doubtless caused by the collapse of chimneys and the breaking of electric connections. These fires were at first confined to the territory south of Market street, and it is said that by 8 a. m. on the morning of April 18 more than fifty fires were recorded. The early failure of the water mains rendered the city helpless and placed it at the mercy of the flames, the fury of which for three days threatened to complete one of the greatest disasters of recent years and to obliterate one of the most beautiful cities in the country. The conflagration was



convenience are arranged in alphabetical order, cover the structures not previously mentioned that were inspected by the writer, the total number embracing nearly every building that was left standing in the burned district. The locations of these buildings can be found by reference to the map, Pl. LVI, and to the panorama, Pl. LV.

ACADEMY OF SCIENCES BUILDING.

The Academy of Sciences building, 819 Market street, views of parts of which are shown in Pls. XXIV, *A*, and XXV, *B*, was of ordinary concrete construction and six stories high, and was completely destroyed.

A six-story annex having brick walls, concrete-filled cast-iron columns, and reenforced-concrete floors, was connected to the main building on the rear. The brick walls of the annex were badly cracked by the earthquake, and the building was subsequently completely gutted by fire. The structure itself passed through a fairly hot fire successfully, although surrounded by buildings which were completely wrecked. Plaster of Paris was used on the concrete-filled cast-iron columns and seemed to stand fire much better than lime mortar. These columns are shown in Pl. XXV, *B*, a view taken from the third floor looking southeast. An interesting feature of the building was the concrete-filled cast-iron column that supported the south wall. Owing to the unequal expansion of the cast iron and the concrete the cast iron failed, bulging from the heat and cracking on cooling, as shown in Pl. XXIV, *A*. The $\frac{3}{4}$ -inch or 1-inch thickness of concrete which covered the reenforcing bars proved insufficient in the basement, where the fire was fairly hot. The heat expanded the bars, thereby ripping off the concrete layer and leaving the rods exposed.

ÆTNA (YOUNG, OR COMMISSARY) BUILDING.

The five-story Ætna Building (Pls. XXIV, *B*; XXV, *A*; XXIX, *B*), on the southwest corner of Spear and Market streets, was occupied by the Sellers Brothers Hardware Company. It was built on piles and had self-supporting walls of gray granite, pressed brick, and terra cotta. The steel columns and girders were fireproofed with expanded metal, plastered. The expanded-metal reenforced-concrete floors rested upon steel girders with intermediate ribs of concrete supported by 5-inch by $\frac{1}{2}$ -inch bands of steel without fireproofing which hooked onto the top flanges of the girders.

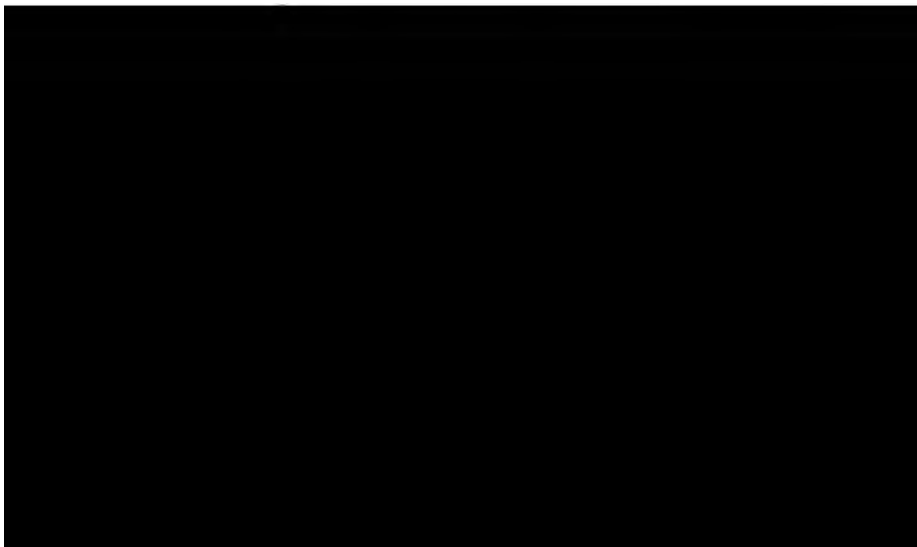
One panel of the fifth floor, which was rather heavily loaded with tin plate, collapsed because of the expansion of the above-mentioned steel bands from the heat, which was sufficient to volatilize the tin from the middle sheets of the pile. The fall of the load of tin

plate caused the failure of the third floor, as shown in Pl. XXIX, *B*. The plaster protection of the columns was in fair condition, and the columns were uninjured. The principal damage from earthquake was to the brick walls, the south and west walls showing a number of cracks. The granite trimmings around the doorway and the terracotta trimmings of the building were badly spalled by the fire, as shown in Pl. XXIV, *B*. The basement floor, which was of concrete 7 or 8 inches thick, was pushed up under the sidewalk, reducing the headroom at this point from 8 feet to 3½ feet, approximately. This bulging was probably caused by settling (Pl. XXV, *A*), as the foundation piling did not extend under the sidewalk.

APPRAISERS' WAREHOUSE (UNITED STATES CUSTOM-HOUSE).

The four-story custom-house building, on Jackson, Washington, and Battery streets, shown in Pl. XXVIII, *A*, passed through both earthquake and fire without injury, although located on the alluvial flats. All the buildings around it were burned, but the fire did not gain a foothold in this building, and there was, therefore, no fire test. As an example of successful resistance of the earthquake test, however, this building stands as a favorable testimony to first-class materials and workmanship. The walls were of brick, with granite ornamentation, and the roof was slate covered. The partitions and cross walls were all of solid brickwork, and the only damage that they sustained consisted of a few cracks in the archways near the stairways on the upper floors.

ARONSON BUILDING.



BEKINS VAN AND STORAGE COMPANY'S BUILDING.

The building in process of construction by the Bekins Van and Storage Company, at the corner of Thirteenth and Mission streets, was the only example of the pure type of reenforced concrete in the city (Pl. XXVII, A). Two of the six floors were erected, the walls being made of brick laid in lime mortar and the floors and columns of reenforced concrete.

The walls were badly cracked by the earthquake, but the reenforced concrete was not injured. Considerable furniture stored in the building was burned, and the heat slightly blistered the under surface of the concrete floor, which was still green at the time of the disaster.

BULLOCK & JONES BUILDING.

The Bullock & Jones Building, on Sutter street west of Montgomery street, is an eight-story steel skeleton with floors of reenforced cinder concrete, hollow-tile partitions and column protection, and bearing walls of ornamental terra cotta and terra-cotta pressed brick. The reenforced-concrete floor arches were haunched between steel girders, but were not continuous over the girders.

The earthquake damaged the outside very considerably. The building is of rather flimsy construction, and it is a wonder that the fire did not wreck it. The terra cotta was badly spalled by the fire, especially around the windows, and the hollow tile failed badly, both in partitions and as column protection. The 3-inch terra-cotta partitions failed generally, and several columns buckled on the third and eighth floors (Pl. XXVI, A). The elevator inclosure, which was plastered on expanded metal, failed, as did also the cast-iron stairways. The wood covering of the floors and the wooden nailing strips were burned. The concrete floor is in excellent condition. A few panels collapsed where the steel girders were displaced. The distorted unprotected beams and girders around openings show strikingly the folly of unprotected steel work.

CALIFORNIA CASKET COMPANY'S BUILDING.

The building which was in process of construction on Mission street between Fifth and Sixth streets by the California Casket Company was seven stories in height and had a steel skeleton and floors of reenforced cinder concrete. The self-supporting walls were built on the sides and rear of brick and on the front of brick faced with sandstone, which was spalled by the heat, although there was no stock and little combustible material in the building. The columns

were fireproofed with concrete. The brick protection around many of the columns was jarred loose, and the brick vaults on the first, second, and third floors were badly cracked around the archways of the openings into them, as shown in Pl. XXIX, A, a view of a vault in the second story. The stairways were constructed of concrete with steel channel horses and were cracked in a number of places, especially at the landings. Some of the wooden window frames were burned, but the fire was not very severe either in the building or surrounding it, the greatest damage resulting from the earthquake. The partitions inclosing stairways and elevator shafts were of the usual flimsy metal lath and plaster type. The walls were so badly cracked as to require partial rebuilding, especially at the southwest and northwest corners.

CALL (CLAUS SPRECKELS) BUILDING.

The Call Building (fifteen stories besides the dome), corner of Third and Market streets, was one of the best-designed skeleton buildings in San Francisco. It was fairly well braced laterally, and the workmanship was first class. It stood the earthquake shock well because of its excellent foundation, which extended 25 feet below the sidewalk and consisted of a grillage of steel beams embedded in concrete. The main defect was in the fireproofing of the floors and columns, in which terra cotta was used, and the greatest damage to the building was from fire. Although some of the diagonal braces were bent and had apparently been stretched so as to take a permanent set, the general behavior of the structure demonstrates that high build-



CHRONICLE BUILDINGS.

The Chronicle buildings, corner of Market and Kearney streets, comprised an old ten-story structure and a new fifteen-story annex that was in process of construction, both shown in Pl. XXX, *B*. The old building consisted of steel beams and protected cast-iron columns, with self-supporting walls, which had a brownstone front up to the second story and were ornamented with terra cotta above. The floor was of hollow tile, filled with cinder concrete and covered with wood. The cast-iron columns were fireproofed with 3-inch hollow tile, and 4-inch hollow tile was used for the partitions. The terra-cotta partitions and fireproofing entirely collapsed. The building appeared to have stood the earthquake shock, and received its principal damage through the fire. The collapse of the western section of the building was probably due to the buckling of the cast-iron columns.

In the annex terra-cotta hollow tile was used for the floor construction, 4-inch hollow tile for the partitions, and 3-inch hollow tile for fireproofing the columns and girders. The curtain walls were built of sandstone, with terra-cotta trimmings for the front walls of the first and second stories, and brick and terra cotta for the remainder. The building was racked considerably by the earthquake, the front walls developing the characteristic X cracks (a number of which may be perceived by a close inspection of Pl. XXX, *B*), due to a lack of diagonal bracing of the steel skeleton. The tiling failed extensively, the lower webs spalling off and the columns buckling in the southwest corner on the upper floors above the roof of the old Chronicle Building. There was little combustible material in the building, and the trim had not started; a few of the wooden window frames only burned; so that the fire test was not great.

CITY HALL AND HALL OF RECORDS.

The city hall (Pl. XXXI) was a brick building, at City Hall avenue, Larkin street, and McAllister street, consisting of steel floor beams and corrugated-iron arches with cinder-concrete filling. It was wrecked by the earthquake and subsequently gutted by the fire. A prominent feature was a central tower, surmounted by a dome built over a structural steel skeleton. Grouped around the dome were a number of cast-iron columns of half-inch metal filled with brick concrete supported on brackets. Some of these columns in falling broke into small pieces. The brickwork was completely shaken from the central tower. The cement-plastered brick walls were laid in lime mortar of generally poor quality and without adequate tie to the steel work. In some places there was an absence

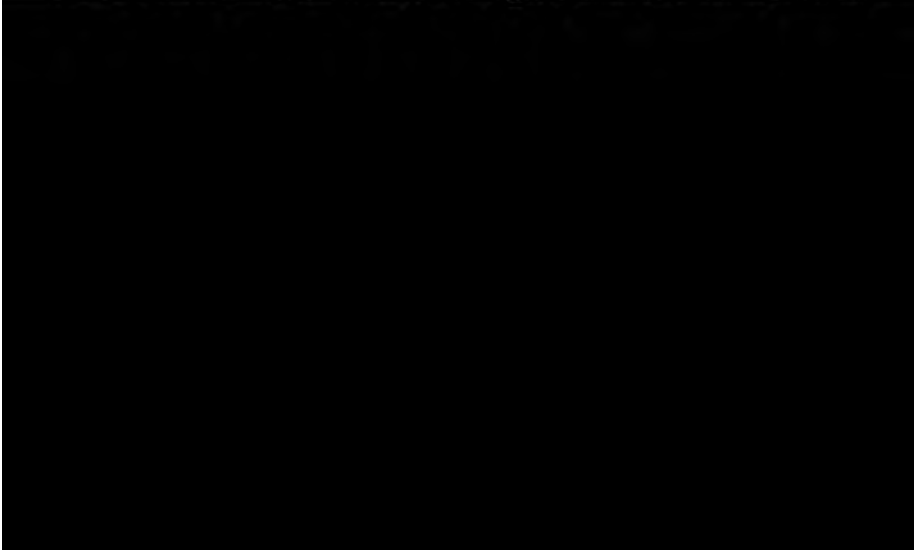
of any mortar, but in others it was very good, the brick walls falling in large masses and the broken bricks showing the mortar to have been the stronger. The massive architectural ornamentations were top-heavy and lacked adequate bracing. The ceiling was formed of corrugated metal against which the mortar plaster was pressed, with intermediate brick partitions where the span of the beams was too great. The expansion of the corrugated-iron arches by the heat produced a rise at the crown, and the softening of the iron caused the arches to fail; they would have been much stronger without the unprotected corrugated iron. In the treasury department a granite column was badly spalled by the fire. The building was a monument of bad design and poor materials and workmanship, and was not, therefore, of such a character that it could be expected to resist successfully the effect of earthquake or fire.

The damage done to the hall of records by the earthquake was not serious, and consisted of the falling of a small section of brickwork from the third story on the west side and other cracks in the walls. The fire, however, destroyed the contents of the building, leaving only the shell standing.

CROCKER BUILDING.

The ten-story Crocker Building, corner of Powell and Market streets, was a steel-skeleton structure, with hollow-tile floor arches, partitions, and fireproofing for columns and girders. The first two stories of the self-supporting walls were granite, and the remainder buff brick with terra cotta.

On the ninth and tenth floors the light Phœnix columns buckled



FAIRMOUNT HOTEL.

The six-story Fairmount Hotel, California, Mason, Powell, and Sacramento streets, was nearly completed, and the only combustible in it was the lumber used in construction. It consisted of a steel skeleton with floors of cinder concrete reenforced with expanded metal. The walls were self-supporting and were constructed of granite backed with brick up to the third floor and of light-colored terra cotta in the upper stories. The ceilings were of the suspended type plastered on metal lath. The original plans called for the columns to be fireproofed with concrete, but because of the greater expense of this material the plans were changed and the expanded metal and plaster partitions were molded around these columns. The result was that even under the moderate heat to which the building was subjected about 40 of the columns buckled, including 23 on the third floor alone (Pl. XXXIV), and the partitions were completely wrecked. The effect of the earthquake shock was principally confined to the west end of the north front. The terra cotta was spalled considerably and the granite only slightly by fire. The exterior damage was not very great.

JAMES FLOOD BUILDING.

The steel-frame twelve-story James Flood Building, on the northeast corner of Powell and Market streets, was constructed with segmental hollow-tile floor arches topped with cinder concrete and suspended ceilings plastered on metal lath. The columns were constructed of Z bars and were filled with common brick to the outer edge of the section and the whole inclosed with 3-inch hollow tile. This tile failed (Pl. XXXV, A), although the fire could not have been very severe, for the wooden floor in the offices was only partly burned and there were a number of wardrobes and switch boxes of wood, besides the door and window frames and wainscoting, which were not burned. The stairways, which had cast-iron horses and marble treads, were in fair condition. The corridors were tiled with marble. The stonework was very slightly spalled by fire, and the principal damage by earthquake was a cracking of the sandstone at several of the entrances (Pl. XXXIII, B).

GRANT BUILDING.

The lower floor of the Grant Building, at the southeast corner of Seventh and Market streets, was used for a bank, the upper floors for offices. It was eight stories high and had a steel frame with cinder-concrete floors, the beams and girders being of solid concrete. The first story had self-supporting walls of sandstone, and the remaining

stories walls of pressed terra-cotta brick, trimmed with sandstone. Hollow tile was used to fireproof the columns and for the partitions.

The cast-iron stairways with marble treads were damaged but slightly. The hollow-tile partitions were badly wrecked, most of them being thrown down. The building was injured considerably by dynamiting, which partly disguised the damage caused by the earthquake.

HOTEL HAMILTON.

The twelve-story apartment house known as the Hotel Hamilton, on the north side of Ellis street between Mason and Powell streets, was a steel-skeleton structure with floors of reenforced concrete and girders and beams of solid concrete. Plastered wire lath served as a fireproofing for the columns, and the suspended ceilings were of the same material. This construction may be seen in Pl. XXXVI, *B*. Four-inch hollow tile was used in the partitions.

The marble treads of the cast-iron stairway were to a large extent calcined. A number of the columns buckled on the first, sixth, and seventh floors, the wire lath being entirely insufficient. This buckling caused the floors throughout the building to settle. The damage by earthquake to the curtain walls was slight. The sandstone finish of the first four floors spalled but little from the heat; the terra cotta above, however, was considerably spalled.

HIBERNIA SAVINGS AND LOAN SOCIETY'S BUILDING.

The two-story bank building of the Hibernia Savings and Loan Society, on the northwest corner of McAllister and Jones streets (Pl.



The granite columns were spalled practically to destruction by fire, as shown in Pl. XXXVI, *A*. The fire in one section appeared to be very hot and caused a collapse of one of the floors, which was followed by the failure of the other floors of that section of the building.

JACKSON BREWING COMPANY'S BUILDING.

The plant of the Jackson Brewing Company, on the southeast corner of Eleventh and Folsom streets (Pl. XXXVII, *B*), was in process of construction and was wrecked by the earthquake, the damage by fire being but slight. The brick walls were laid in lime mortar of poor quality. The steel beams and girders were supported by cast-iron columns. Many of the various steel members were bolted together with an insufficient number of bolts, the girders and beams resting upon the walls without any tie; the columns, girders, and beams were not fireproofed, and in the eastern half the concrete floor slabs, 6 inches thick, were without reinforcement. Several persons were killed by the collapse of the tower. That this building should have been wrecked is not surprising, as the design was bad and the material and workmanship were very poor.

HALL OF JUSTICE.

A steel frame and floors of cinder concrete reenforced with expanded metal were used in the Hall of Justice, at the corner of Kearney and Washington streets. The earthquake largely wrecked this building (Pl. XXXIX, *A*). The cupola of light steel angles collapsed from the heat after being racked by the earthquake. The walls were laid in lime mortar, and the floor panels were stiffened, as in the *Ætna Building*, with 5 by $\frac{1}{2}$ inch steel bands. The floors were wood covered and were burned. The suspended ceilings were of plastered expanded metal lath, the partitions of 3-inch expanded metal, plastered, while the columns had a double layer of plastered expanded metal with a $1\frac{1}{2}$ -inch dead air space between. The suspended ceilings failed, as shown in Pl. XXXV, *B*, a view taken on the second floor. One of the central basement columns buckled and collapsed 18 inches, presenting the appearance of having punched a hole in the floor. Two of the six-cell prison cages fell through the floors into the basement. The cast-iron stairways with marble treads are in fair shape.

KAMM BUILDING.

The seven-story L-shaped Kamm Building, on Market street, west of the Call Building and adjacent to it on two sides, had a steel skeleton and self-supporting sandstone walls. The floors were of reenforced
, covered with wood, with hollow partitions and

pended ceilings of plastered wire lath, the steel columns, beams, and girders being also fireproofed with plastered wire lath.

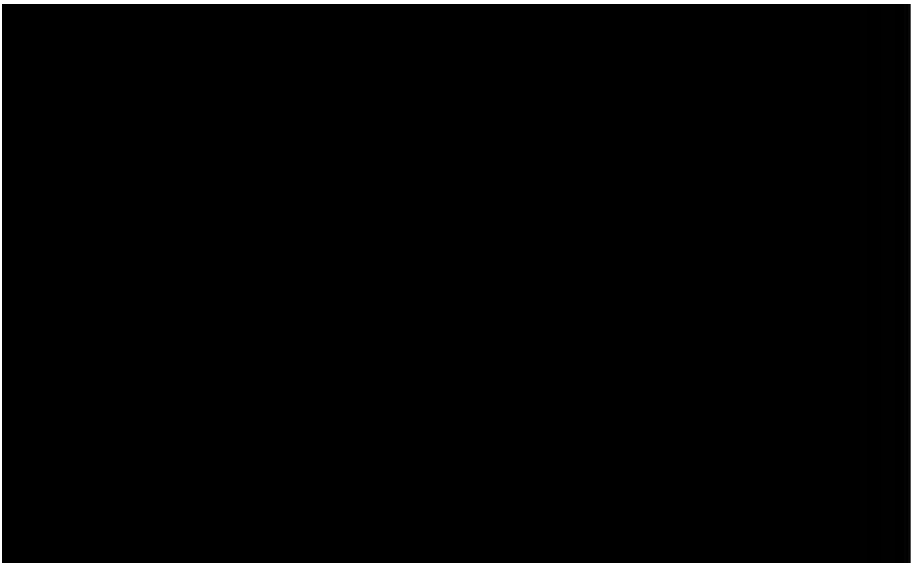
The rear structure collapsed when a number of columns in the basement buckled under the intense heat produced by the burning wall paper, of which there was a large quantity stored in the basement.

KOHL (HAYWARD) BUILDING.

The Kohl Building, on the northeast corner of California and Montgomery streets, which presented a number of interesting features, is of a modern type of steel-skeleton construction, 11 stories in height. The floors were of concrete, reenforced with expanded metal, and the columns were incased with expanded metal, plastered. The partitions were made of hollow tile, with metal-covered frames, doors, and windows. The suspended ceilings were of plastered expanded metal.

The earthquake did but little damage, breaking a few panes of glass and loosening the marble wainscoting. There were also a few cracks in the stone facing at the southwest corner of the first floor. The first, second, third, fourth, and part of the seventh floors were burned, the remainder of the building being undamaged. The structure was surrounded by a series of rather low buildings, and the fire was not severe either on the outside or inside. The character of the inside trim prevented to a considerable degree the spread of the flames. One defect in the construction was in the use of plate glass instead of wire glass for the doors and windows.

MAJESTIC THEATER.



MERCHANTS' EXCHANGE BUILDING.

The recently constructed modern office building known as the Merchants' Exchange, on California street between Montgomery and Sansome streets, caught fire from the outside and its contents were destroyed. The edifice was 13 stories in height, with steel skeleton, fireproofed with plastered wire lath and reenforced-concrete floors. The floors of the rooms were of wood; the corridors were floored and wainscoted with marble. The fireproofing of the columns consisted of two layers of quarter-inch wire lath with a dead air space between, except those which were bricked into the outside walls. The suspended ceilings and partitions were likewise of plastered wire lath, and the same material formed the walls of the "fireproof" vaults. The curtain walls were of brick on the sides and rear; on the front the first two stories were of granite, the remainder being pressed terra cotta with terra-cotta trimmings. The heat of the fire was sufficient to calcine a large portion of the wainscoting and the marble treads of the cast-iron stairways. Though not completely destroying it, the fire burned the life out of the plaster, all of which will have to be renewed. The rear walls were cracked by the earthquake. The enameled brickwork of the light well (Pl. XL, A) also shows earthquake cracks, and is badly spalled by the fire. The stonework was slightly spalled by the heat. The metal frames between the windows opening into the court were buckled, the cinder-concrete fireproofing being insufficient. The terra-cotta trim in the light well was also badly spalled.

MILLS BUILDING.

The eleven-story Mills Building, at the northeast corner of Bush and Montgomery streets, had a steel skeleton with hollow-tile fireproofing and hollow-tile partitions. The floors were also of hollow tile topped with cinder concrete and covered with wood in the offices; the tiling and wainscoting of the corridors were of marble.

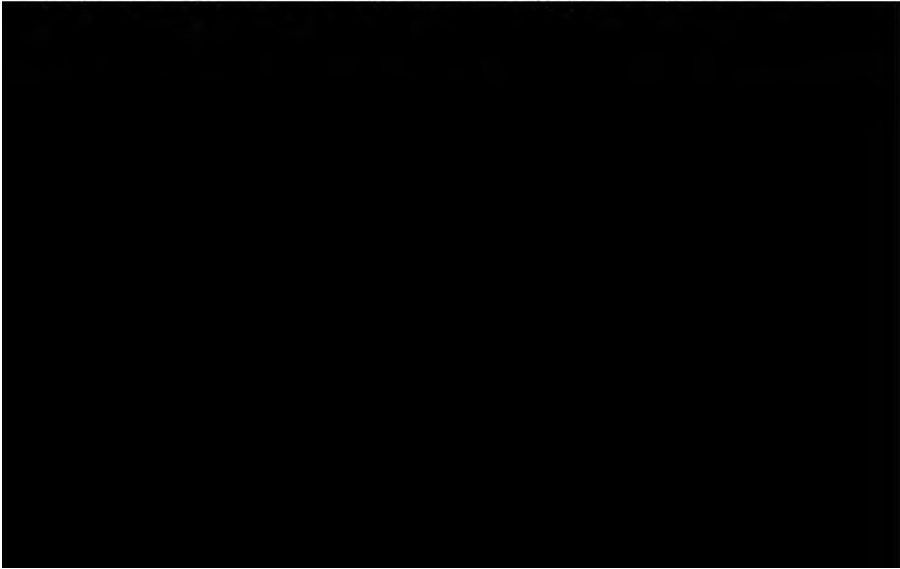
The walls were racked by the earthquake. The hollow tile failed and left the steel skeleton exposed to the fire. Just how seriously it was damaged is problematical; four of the basement columns buckled (Pl. XL, B), the lower webs of the floor tiles failed over large areas (Pl. XLV, B), and the partitions and the marble treads of the cast-iron stairways were destroyed. In the light well the window casings were distorted by heat because of insufficient fireproofing, and the terra cotta, granite, and exterior trim of the wall were badly spalled. Owing to the failure of the floor tile many safes fell through the several floors. The building should be rebuilt.

UNITED STATES MINT.

The massive three-story Government building occupied by the United States mint, at Fifth and Mission streets (Pl. XXXVIII), which was not damaged to any appreciable extent by the earthquake, was inspected in company with the superintendent, Mr. Leach. One of the interior walls was weakened by a break in the sewer which ran under it, and one of the chimneys was cracked at the top. This structure, which is located at the intersection of two wide streets, is built on soft alluvium, but rests upon a substantial pile foundation. The bearing walls were of solid brick faced with granite, the northwest face of which was badly spalled by fire (Pl. XXXVIII, *B*). The floors consisted of brick arches between steel beams, finished in cement. They were supported by cast-iron columns, which were unprotected except where they were incased by the heavy brick wall partitions. The doors and windows were of wood glazed with plate glass, the windows on the first and second floors being fitted with folding inside iron shutters. The roof and northwest side of the third story caught fire from without, but as an artesian well provided an independent supply of water the fire was prevented from gaining a foothold, and the building was but slightly damaged.

MONADNOCK BUILDING.

The ten-story Monadnock office building, on the south side of Market street between the Palace Hotel and the Call Building, was in process of construction and was damaged by the earthquake and by dynamiting in the vicinity, besides being gutted by fire.



columns. While the jacking up closes the cracks, it can not restore the original strength of the connection, which although not entirely gone has been reduced to a very small percentage of its former value.

MURPHY BUILDING.

The columns of the five-story Murphy Building, at the corner of Kearney and California streets, were constructed of corner angles latticed and filled with cinder concrete, the whole being incased with plastered metal lath, with a dead air space between. The floors consisted of cinder-concrete arches between channels.

This building was completely gutted by the fire, although the structure itself was left in fair condition. The metal-lath ceilings and partitions stood the test fairly well, though some of the partitions were buckled out of shape. A view of this damage on the third floor is shown in Pl. XLI, *B*. The terra-cotta trimmings and the copper work around the bay windows were badly damaged by fire.

MUTUAL LIFE BUILDING.

The nine-story Mutual Life Building, at the southeast corner of Sansome and California streets, was fireproofed throughout with terra-cotta hollow tile, with hollow-tile partitions. The treads of the cast-iron stairways and the wainscoting and tile of the corridors were of marble. The office floors were constructed of cinder concrete covered with wood.

The damage to this building from the earthquake was very slight. The fire in the building, while not severe, was sufficient to cause the failure of the tile fireproofing of the roof trusses, which collapsed from exposure to heat (Pl. XLII, *A*).

PACIFIC STATES TELEPHONE AND TELEGRAPH COMPANY'S BUILDING.

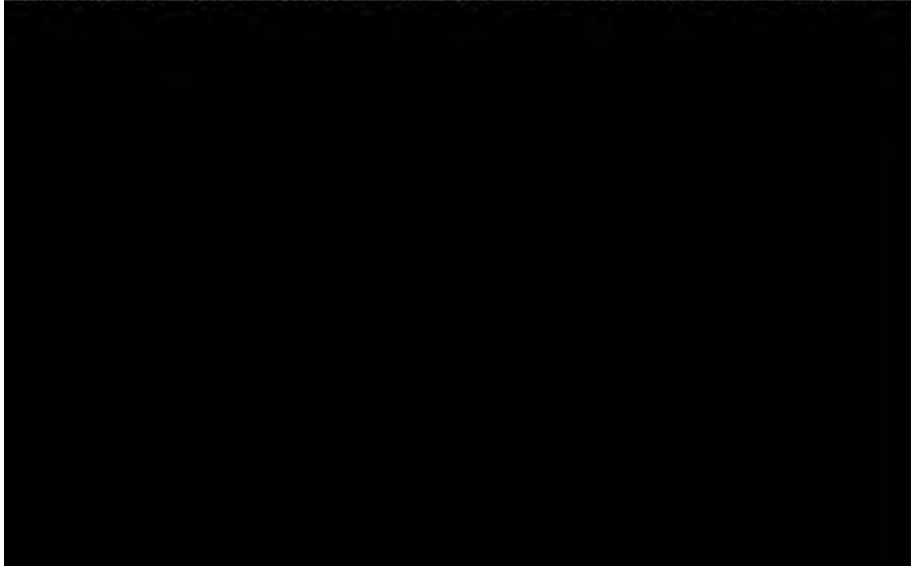
The recently completed eight-story building of the Pacific States Telephone and Telegraph Company, on Bush street between Grant and Kearney streets (Pl. XLI, *A*), embodied many good and a few bad features of construction. The side and rear walls were of brick, and the front was of terra-cotta pressed brick and terra-cotta trimmings. All the walls were self-supporting. The floors were of reinforced concrete between steel beams, and the ceilings for all floors above the basement were suspended metal lath, plastered.

The walls were cracked somewhat by the earthquake, and the pilasters on the exterior were spalled. The girders and columns supporting the floors were fireproofed with concrete and were in excellent shape after the fire. The window protection was excellent; the front was provided with Kinnear rolling shutters, with plate-glass metal-covered windows, while the side windows had

metal-covered sash and frames, with wire glass, and tin-covered sliding shutters. The earthquake racked the front sufficiently to prevent the shutters from working. The heat produced by the burning insulated wire and other supplies was high and protracted. The reenforced-concrete beams of the roof were weakened by heat and will have to be replaced. The concrete in general, however, stood this trial exceedingly well in view of the protracted high temperature. The fire caught through an unprotected rear door in the southwest corner, and the break in the roof made possible a very hot fire, which melted glass and even welded nails. The concrete floors and the column protection were not damaged in the slightest. If the methods of fire protection had been consistent throughout, it is probable that this building would have escaped without damage.

POST-OFFICE BUILDING.

The writer made a thorough examination of the post-office building, on Mission street between Sixth and Seventh streets, in company with J. W. Roberts, superintendent of construction, of the Supervising Architect's Office. This three-story structure rested on a foundation consisting of steel beams incased in concrete, carried through the soft alluvium to a hard gravel, the depth varying from 30 feet at Seventh and Mission streets to 12 and 14 feet at the opposite corner. The building had a steel frame, expanded-metal and concrete floors, and plastered expanded-metal suspended ceilings. All partitions or interior walls were of terra-cotta hollow tile, laid with full joints of Portland-cement mortar, the terra-cotta work being first class in every particular. The corridors were tiled and wainscoted with marble.



The worst damage appeared to be in the interior walls of hollow tile, which were very extensively cracked, especially on the first and second floors. The plaster finish on the hollow-tile partitions strengthened them very considerably. One portion of the mosaic ceilings of the corridors on the main floor was laid in Portland-cement mortar on a flat tiled arch and was badly cracked; another portion, laid in Portland cement against wire lath plastered, was undamaged. In the mail-handling room the end wall was moved out of plumb by the earthquake, and the enameled-brick covering of several columns was shaken off. The only damage done by fire was in the district-court room, in the north corner of the third floor, which caught from without and was burned out, together with two adjacent rooms on the northwest front. On the northeast end of the first floor the exterior stonework was also spalled by fire.

A very considerable amount of damage was done by the dynamiting of near-by buildings, which was so severe as to smash the glass and blow out the window and door frames. In many places the marble wainscoting on the opposite side of the corridor was shaken loose. Probably 20 per cent of the injury done to the building is in the glass, marble, and finish. The building is substantial, and the materials and workmanship are first class.

RIALTO BUILDING.

The eight-story Rialto Building, at the southwest corner of Mission and New Montgomery streets, had a steel frame and reenforced cinder-concrete floors. The partitions were of hollow tile and the ceilings of suspended expanded metal, plastered. The columns were fireproofed with two layers of plastered expanded metal for all floors except the basement, where only one layer was used. The corridors had mosaic floors, and the stairways were of cast iron with marble treads.

The building was considerably racked by the earthquake and was further damaged by fire and dynamiting (Pl. XLVIII, *B*). The fire was only moderately hot, but was sufficient to destroy the fireproofing of two columns in the northeast corner of the basement, so that they failed by buckling (Pl. XLVIII, *A*), causing extensive wrecking of the upper floors. The failure of the column protection was caused by the expansion of a pipe inside of it. The terra cotta around the entrance to the building was cracked by the earthquake.

ST. FRANCIS HOTEL.

The twelve-story St. Francis Hotel, in West Union square, at the corner of Geary and Powell streets, was of a modern type, having a reenforced-concrete floors, with suspended ceilings.

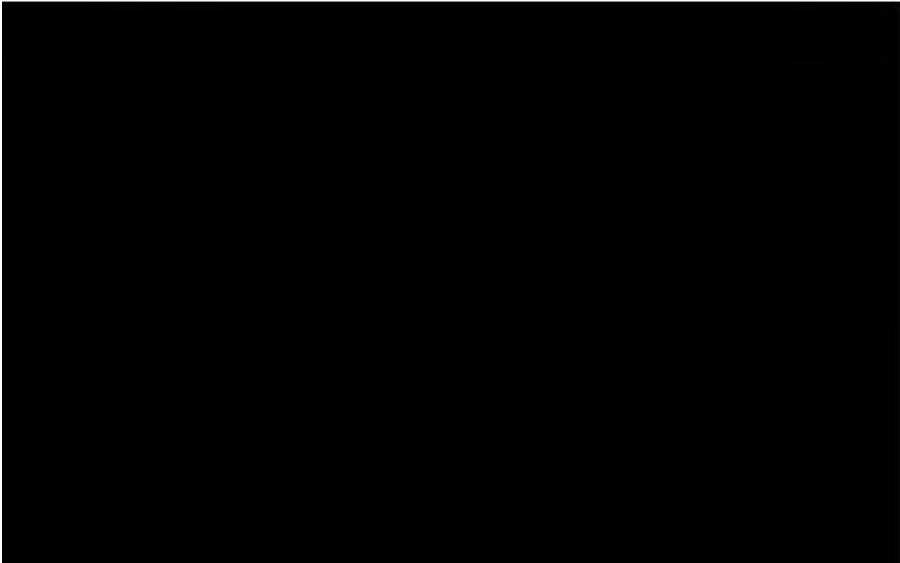
tered on wire lath. The fireproofing of beams and girders in the basement and first floor was concrete; in the upper floors it was wire lath and plaster. The columns of the first floor were fireproofed with concrete, those in the basement with brick, and on the upper floors 4-inch hollow tile was used. On the first floor the concrete was omitted for 18 inches at the top and a cap of plaster of Paris used; this was a serious mistake and might have caused trouble.

The stone was slightly spalled by fire and on the front was slightly damaged by the earthquake. The enameled bricks of the light well were badly spalled by heat. Two columns failed by buckling. The fire was not severe, and the damage was not very great.

SCOTT BUILDING.

The Scott Building, on the south side of Mission street between First and Fremont streets, was a four-story structure with a mansard roof. Machinery sales rooms occupied the two lower floors, printing and lithographing offices the upper. The building was constructed of steel girders and beams, with reenforced-concrete floors, suspended ceilings plastered on metal lath, and unprotected cast-iron columns. The curtain walls were carried on steel work which was unprotected over the windows.

The mansard roof and the upper part of the walls were destroyed by the earthquake. The western section was wrecked by dynamite. The ceilings failed, and the stonework spalled slightly. The fire was not severe, to judge from the appearance of the undamaged naked cast-iron columns.



SLOANE BUILDING.

The seven-story Sloane Building, on Post street between Grant and Kearney streets, had bearing walls of terra cotta, brick and terra-cotta trimmings, and a framework of cast-iron columns and steel beams and girders. The partitions and fireproofing were of expanded metal, plastered, and the floors were of concrete, reenforced with expanded metal. All columns except those in the basement were fireproofed with expanded metal, plastered.

There is every indication of a very hot fire in the basement, which buckled several of these unprotected columns, causing a collapse in the central portion of the building (Pl. XLIX, A).

SPRING VALLEY WATER COMPANY'S BUILDING.

The City of Paris Dry Goods Company occupied the two lower floors of the Spring Valley Water Company's building, at the southeast corner of Geary and Stockton streets, the remaining four stories being used for office purposes. The building, a general rear view of which is shown in Pl. L, A, had a steel skeleton, the partitions, column protection, and floor arches, the lower web of which spalled off extensively, being of hollow tile. The floor arches were topped with cinder concrete and covered with wood. The columns in the southeast corner of the basement buckled, and the upper stories collapsed. The hollow-tile partitions were in bad condition, and the 2-inch tile on columns failed generally. Where the tile ceilings were unprotected the webs spalled extensively; where there was a suspended ceiling remaining in position the tiles were in fair condition. The cast-iron stairways with marble treads were also damaged. There were a few slight earthquake cracks along the Stockton street side, and the south wall had a vertical crack.

UNITED STATES SUBTREASURY.

The four-story brick subtreasury building, on Montgomery street between Commercial and Clay streets, had rolling shutters on the lower front windows and a combination of wood and concrete floors. The wood burned, causing the collapse of that portion of the building. The remainder of the concrete-floor portion seemed to be in fair condition.

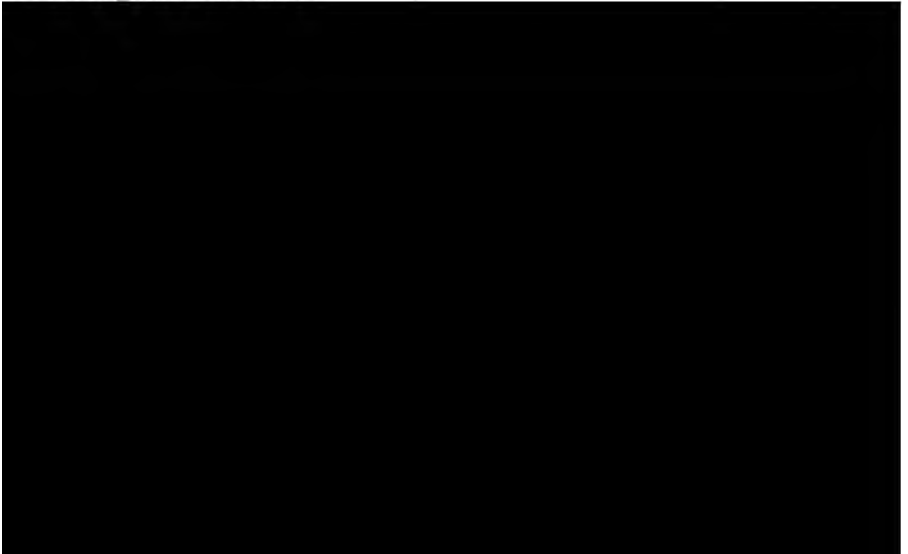
UNION TRUST COMPANY'S BUILDING.

The Union Trust Company's ten-story office building, on the corner of Market and Montgomery streets, was constructed with a steel frame. The front walls of the first two stories were granite; the

remaining walls were of pressed terra-cotta brick, with terra-cotta trimmings. The floors and partitions were of hollow tile, and the girders, beams, and columns were fireproofed with the same material. The floors were topped with cinder concrete covered with wood, except in the corridors, where cement finish was used. The cast-iron stairways had marble treads. The granite walls were spalled around the openings by fire. The hollow-tile partitions failed extensively, and the lower web of the floor tile spalled over large areas. The fire was not intense, and the steel appeared to be in fair condition except on the ninth and tenth floors. The extent of the damage can be seen in Pl. L, B, a view on the ninth floor. The steel trusses on the tenth floor were very much distorted by heat, owing to the failure of the hollow-tile fireproofing.

VOLKMAN BUILDING.

The lower floor of the Volkman Building, on the north side of Jackson street between Montgomery and Sansome streets, opposite the unburned block near the appraisers' building, was occupied by a branch of the post-office. The structure was surrounded on the sides and rear by completely gutted buildings, and its escape was probably due to its protected openings. The windows were glazed with wire glass and the sash and frames were metal covered. The rear doors were equipped with Kinnear rolling shutters. A few windows were so badly damaged that they will have to be replaced, but the building was only slightly injured, for the fire did not gain a foothold.



ASPECTS OF THE FIRE DISASTER.

The San Francisco fire, which lasted three days, was one of the greatest conflagrations of recent times. The loss by fire was greater than it should have been, by reason of the failure of the cast-iron water mains in the city; although the loss must necessarily have been great because of the character of the buildings, 90 per cent of which were frame. This disaster demonstrated that the lessons from the Chicago and Baltimore fires are still unlearned. The same faults in construction continue to be repeated. The only sure way to remedy grave defects of this character is to enact strict building laws which will compel an observance of the essentials for fireproof structures.

The conditions at San Francisco were unusual, and even had not the water supply failed it is doubtful whether they could have been controlled, for the reason that it would have been impossible for the fire department to handle efficiently so many fires at a time, especially as there were so many nonfireproof structures. Large conflagrations demonstrate that there is no such thing as a fireproof building. To label one as such is bad practice, since it gives a false sense of security and induces a relaxing of necessary precautions.

FIRE HISTORY AND RECOMMENDATIONS OF INSURANCE BOARDS.

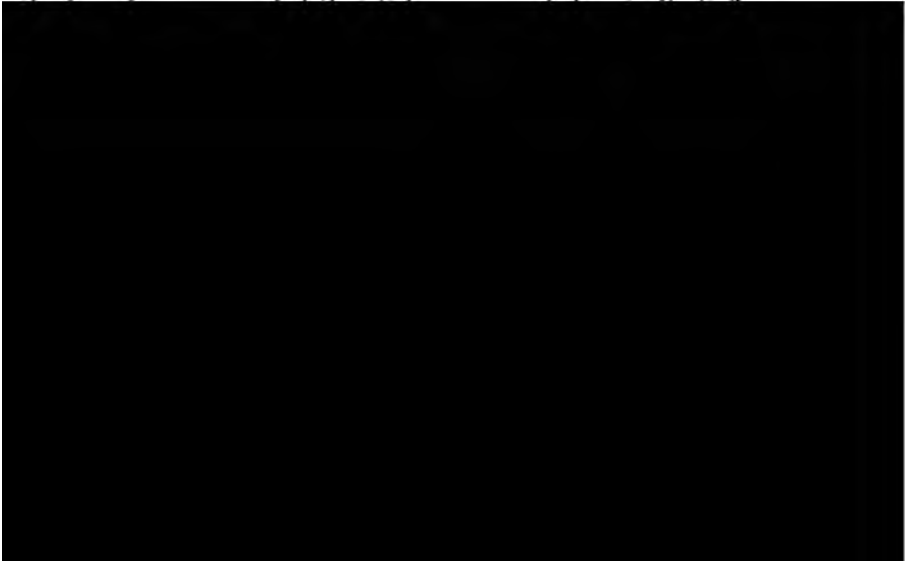
It is claimed that the recorded destruction by fires in San Francisco up to 1899 was excessive, showing an average loss between two and three times that expected in cities having ordinary fire protection. In every year since 1899, except 1903, although the number of fires increased materially, the average loss per fire remained moderate. In any of these years the number of fires involving losses of \$40,000 or more did not exceed two. In 1903 there were ten large fires, each involving a loss of more than \$40,000, thus bringing the total up to a high figure; and at each of these fires the greater portion of the loss was to the contents rather than to the buildings.

In October, 1905, a board of fire-insurance experts presented the report of an examination made under the direction of the National Board of Fire Underwriters on the fire-hazard conditions of San Francisco. This report is extremely interesting and shows clearly how a body of trained experts can accurately locate defects and predict the consequences likely to result from them. The criticisms and recommendations embodied in the report are particularly pertinent to San Francisco; and when the conditions prior to the great fire are considered, the conclusion must be inevitable that no other result of these conditions—a general conflagration which swept the city—could reasonably have been expected. Attention was called to the following principal features of construction affecting the fire hazard

in the business district: (1) Bad exposures and unprotected openings; (2) poor construction; (3) an absence of sprinklers or of any of the modern protective devices; and (4) excessive height in non-fireproof structures. It is stated that in the congested district about 2.2 per cent were fireproof, 68.3 per cent were wooden joisted brick, and 29.5 per cent were frame buildings. A very bad feature lay in the fact that a large number of so-called "fireproofs" were surrounded by nonfireproofs. The mixture of dwellings and minor mercantile buildings surrounding the congested-value district also greatly increased the hazard.

The board recommended the municipal ownership of the water supply. They considered the present supply ample in amount for the existing requirements, but subject to a decided probability of local failure in emergencies, owing to faults in the distribution system. They deemed it very desirable to increase the capacity of the existing system and to install at the earliest possible date a separate fire-main system, and recommended that all dead ends of pipe mains be connected with the network wherever practicable. They advised that the system of distribution be equipped with a sufficient number of gate valves, so located that no single case of accident, breakage, or repair to the pipe system would necessitate the shutting from service of a length of main greater than the side of a single block (a maximum of 500 feet) in important mercantile manufacturing districts, or than two sides of a single block (a maximum of 800 feet) in other districts.

The building code was found to be satisfactory on the whole, but



of modern protective devices, and the prevailing high winds, made the probability feature alarmingly great.

They advised that the inadequate force of four building inspectors be at least doubled, and that the building laws be rigidly and impartially enforced.

They found the fire department to be an efficient force, well organized under an exceptionally competent chief, and though weak in powerful engines, otherwise fairly well equipped, the number of engine companies being particularly large.

In their report the board summarized the situation in San Francisco as follows:

While two of the five sections into which the congested-value district is divided involve only a mild conflagration hazard within their own limits, they are badly exposed by the others, in which all the elements of the conflagration hazard are present to a marked degree. Not only is the hazard extreme within the congested-value district, but it is augmented by the presence of a compact surrounding, great-height, large-area, frame-residence district, itself unmanageable from a fire-fighting standpoint by reason of adverse conditions introduced by the topography. In fact, San Francisco has violated all underwriting traditions and precedents by not burning up; that it has not done so is largely due to the vigilance of the fire department, which can not be relied upon indefinitely to stave off the inevitable.

FIRE-RESISTING QUALITIES OF STRUCTURES AND STRUCTURAL MATERIALS.

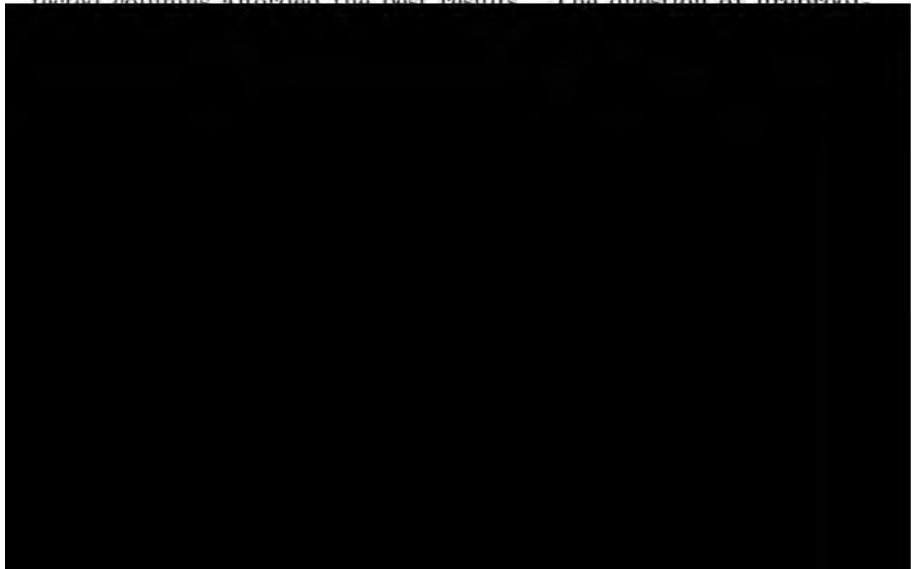
The fire which has practically destroyed San Francisco has more than fulfilled this prophecy. The destruction was greater than in the Baltimore fire because the fire was hotter, owing, as has been pointed out, to the inflammable surroundings and the unprotected openings, and to the unchecked sway of the flames. The heat was so intense that sash weights and glass melted and ran together freely. In some places the edges of broken cast-iron columns softened, the tin coating in piles of tinned plate volatilized, even in the middle of the piles, and nails were softened sufficiently to weld together. (See also Pl. LI, A.) The maximum temperature, lasting for a few minutes in each locality, was probably 2,000° or 2,200° F., while the average temperature did not exceed 1,500° F.

Nearly all the so-called "fireproofs" were gutted and their contents destroyed, the fire damage done to these buildings being fully 60 per cent. The early collapse of protected steel frames owing to the failure of the fireproofing was of common occurrence. The extent of the damage to a building from fire can be determined only after the débris and wreckage have been removed and will then be found to be much greater than was at first supposed. This is particularly true of steel structures in which the effect of fire is den by the débris.

Of perhaps thirty fireproofs of good height with reenforced-concrete floors, all but two had steel frames. Steel beams and columns were generally protected with metal lath and plaster, cinder concrete, or terra-cotta tile. Practically all floor construction consisted either of hollow terra-cotta tile or reenforced concrete. Ceilings of light angles and metal lath, plastered, suspended from floors, served as additional means of fireproofing, by keeping the fire from coming into direct contact with the flooring material. Steel beams in many buildings had no protection, even where concrete filled, except this subceiling. The lower webs of floor tile came off to perhaps a greater extent than in the Baltimore fire. It is said to be impossible to procure a suitable hard-wood sawdust on the Pacific coast, such as is required in the manufacture of porous terra-cotta tile. The tile used is therefore denser and of poorer quality. The behavior of reenforced-concrete floors was most excellent.

Partition walls were in a very few buildings of brick. As a rule, however, they were either of 3-inch hollow terra-cotta tile or metal lath, plastered.

The matter of column protection is very important, as the number of failures in the San Francisco fire was particularly large, especially in the Fairmount Hotel (Pl. XXXIV). Unprotected cast-iron columns failed as a result of unequal expansion caused by the lugs. A few light cast-iron columns filled with concrete came through without damage, and at the Academy of Sciences (Pl. XXIV, A), as already described, cast iron failed around a concrete core, which carried the load. Brick-filled columns gave fair satisfaction, but concrete-protected columns afforded the best results. The question of fireproof



mental purposes. The behavior of the metal-covered woodwork in the Kohl and other buildings was satisfactory and immensely better than that of the naked wood. It is certain that a building may be finished and trimmed and even decorated with noninflammable materials. Although the additional security of such materials in case of fire does not appeal to owners and architects as compensating for their extra cost in comparison with wood or other inflammable materials, the building laws should nevertheless compel this type of construction.

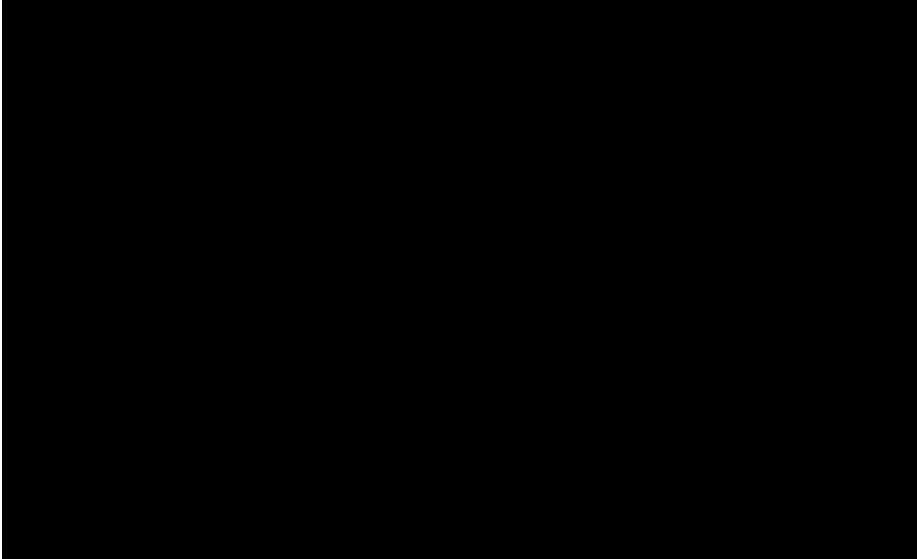
The loss in ornamental stonework was particularly great, especially in the case of marble, which in many structures was completely calcined. Brickwork suffered most from the earthquake and least from fire, and sandstone splintered less than granite, which suffered severely, a number of badly spalled columns showing how futile this material is for other than ornamental purposes. Concrete proved superior to brick as a fireproofing medium.

It is estimated that over 80 per cent of the so-called "fireproof" safes failed. Many valuable records and much other property were thereby destroyed. An ordinary fireproof safe was of absolutely no value, and the contents of nearly every one were destroyed. In many office buildings so-called fireproof vaults were constructed of hollow tile or plastered metal lath, being formed partly by the partitions of the rooms, and were so flimsy that they yielded readily to the flames. In Pl. LII can be seen groups of so-called "fireproof safes," many with walls 20 inches or more thick, which failed to serve the purpose for which they were designed. Pl. LII, *B*, shows part of a collection of over 50 of these "safes" whose contents were destroyed. In a number of jeweler's safes silver and other precious metals were melted. The warping of the doors also resulted in the loss of the contents in many vaults, even where they were otherwise well designed. In short, fireproof vaults and safes behaved in the San Francisco fire very much as they did in the Baltimore fire. Little progress seems to have been made toward the production of a satisfactory fireproof safe. The only really fireproof vault is one with brick or concrete walls not less than 10 inches thick. The cement-filled metal safe proved to be a very good type of fireproof. Even in well-designed safes and vaults, great care must be exercised in opening them after they have been exposed to fire. Time should be allowed for the temperature in the interior to become reduced to somewhere near the temperature of the surrounding air, as otherwise the contents may be destroyed by spontaneous combustion on exposure to the air. Pl. LII, *A*, is a view of one of the oldest vaults in San Francisco, that of the old Wells, Fargo & Co.'s Express, which passed the fire test satisfactorily.

The writer is of the opinion that the present commercial hollow

terra-cotta tilè is largely, if not entirely, devoid of merit for fireproofing purposes. Even when it is of the best grade and workmanship it can hardly be considered a first-class building material. At a comparatively low temperature the tiles fail, the thin webs spalling from unequal expansion. A more porous tile, with thicker webs keyed together and laid in Portland-cement mortar with tight joints, would unquestionably be more suitable for the purpose. It may be true that in case of repairs after a fire damaged tile of the usual commercial type can readily be detected and renewed. Terra-cotta tiling may, however, allow sufficient heat to pass through it to soften slightly the steel member which it encases and still remain in position, thus hiding the defect. Several examples of this condition were found.

The advocates of terra-cotta tile contend that concrete may be seriously damaged by dehydration without noticeable change in its appearance. While this contention may be justified, it should be noted that any weakness or softness may be as readily detected and repaired in concrete as in terra cotta. Concrete, moreover, has the great advantage of being a nonconductor of heat, and so will withstand a prolonged heat before the damage extends to any great depth; and it usually remains in place, maintaining its protective qualities. The value of a structure or of a method of fireproofing is determined largely by ascertaining what portion of the structure is left available for use after the fire. The word "fireproof" is of course a misnomer, for no building is absolutely fireproof; and the resistance offered to fire is one of degree only, for if the heat be sufficiently high and prolonged, nothing can withstand it. The best materials



is likely to fail through rupture of the steel mains, it is highly desirable to have an independent supply, as from an artesian well, with the necessary pumps and service pipe.

In the matter of fireproofing, certain definite recommendations may be deduced from the San Francisco conflagration, as follows:

1. Exterior openings should be protected by the use of metal frames or metal-covered frames with wire glass, or exterior iron shutters or interior metal-covered shutters, or both exterior and interior shutters.

2. The structural members, especially the columns, should be better protected, preferably with solid concrete; they may be filled with brick and covered with terra cotta or with a double layer of cement-plastered metal lath, with an air space between.

3. There should be a better type of partition, the present plastered metal lath or hollow terra-cotta tile being inadequate. Reinforced-concrete partitions are much more efficient.

4. All combustible trim should be eliminated. The fire loss from this item is high, and it should be so designed as to be replaced readily and cheaply.

5. Attic floors and roofs should be designed to resist fire. In many buildings the roof members were not fireproofed and their failure caused great damage.

6. Buildings should be so arranged that the fire could be confined to a single room.

WATER SUPPLY AND OTHER METHODS OF FIGHTING FIRE.

In connection with the matter of the fireproof construction of buildings above referred to, certain suggestions may be made in regard to private and public facilities for fighting fire, as follows:

1. An independent water supply and other facilities for fighting the fire from either within or without should be provided.

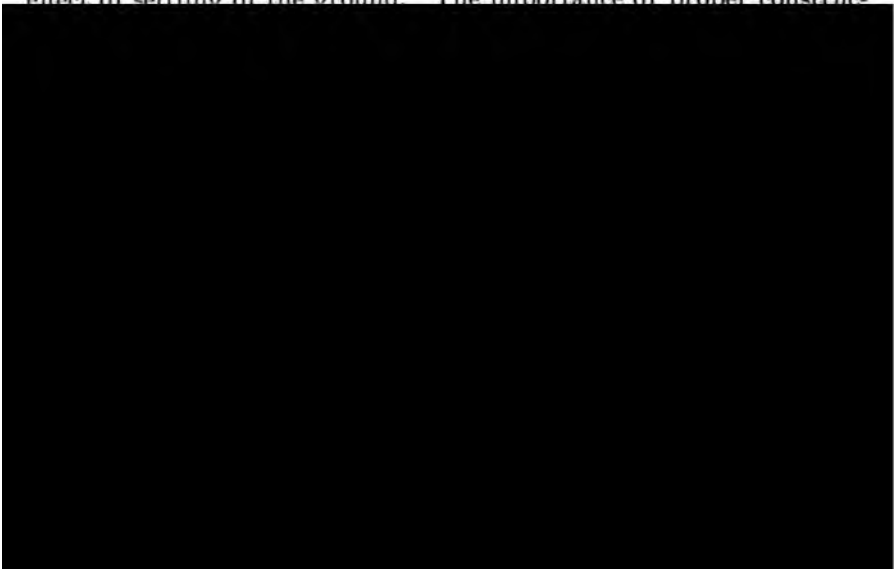
2. Another very important problem, at least so far as San Francisco is concerned, is that of the public water supply. The failure of a gridiron system of cast-iron pipes seriously cripples a water supply, no matter how large may be the storage. It is also evident that greater care must be exercised in the laying of these mains, especially in filled ground or alluvial soil, where failures are likely to occur. A system of by-passes should be provided, so arranged as to permit the cutting out of portions which are broken or otherwise damaged, and some system should be installed for quick repairs under emergency conditions.

3. A high-pressure service operated from the bay, using salt water, would also be an essential feature. This service might necessitate a floating pumping station, as recommended by the National

4. The use of explosives, such as dynamite, for fighting a fire should be greatly restricted and intrusted to experts only, or else abandoned. It is extremely doubtful whether the progress of a fire can be checked by dynamiting in advance of the fire without the removal or thorough wetting of the débris. Such procedure would have been impossible in San Francisco, as the water supply was unavailable and it was impossible to carry away the wreckage. The indiscriminate dynamiting did more harm than good, for the reason that the concussions injured the surrounding buildings, as shown, for example, by the extensive damage done at the post-office. Back firing would have been equally bad, because to apply this method successfully plenty of water for controlling the fire is necessary. A fire stop is the best way of checking a conflagration, and a fireproof structure makes the best fire stop if it has well-protected openings.

GENERAL LESSONS OF THE EARTHQUAKE AND FIRE.

In considering the results of the destruction which was wrought by the earthquake and fire there appear certain salient features from which conclusions may be drawn. In regard to the possibility of the erection of an earthquake-proof structure, it is apparent and universally admitted that it would be impossible to build on the fault line a structure which could withstand the effect of a slip. Furthermore, it is realized that in building near the fault on soft or alluvial soil extra precautions must be taken; for example, location of the San Francisco water mains in ground of this character was unwise, since it is difficult to design a waterworks system capable of resisting the effect of settling of the ground. The importance of proper construc-



The structures which suffered most from the earthquake were—

1. The municipal and county buildings. The greatest destruction was sustained by these buildings, which were generally badly designed and poorly constructed of inferior materials, while the well-built, substantial Government buildings suffered less.

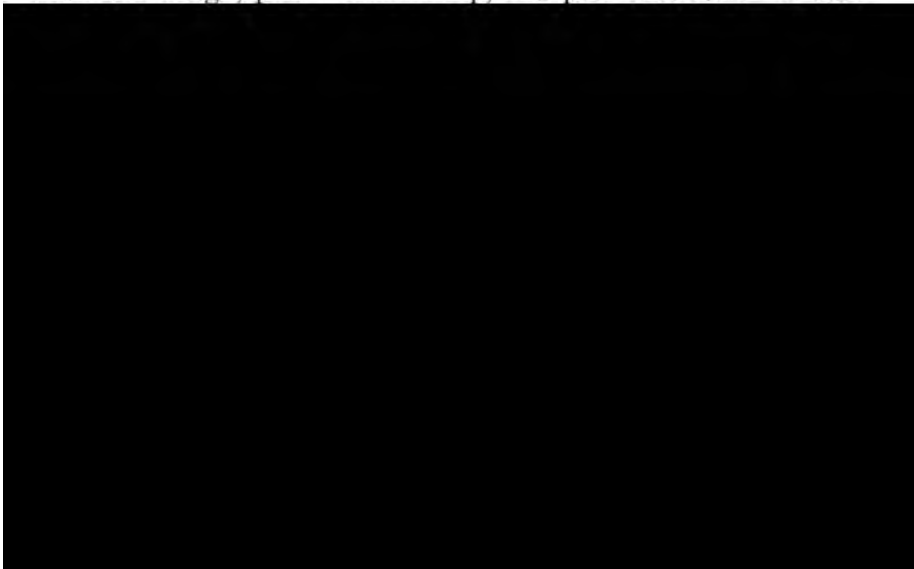
2. Lightly and flimsily constructed wooden buildings. Well-constructed wooden buildings generally withstood the shock, but those that were flimsily built, resting upon posts or equally insufficient foundations, collapsed, even where they were fairly well designed. The essentials of earthquake-resisting power are vertical continuity, adequate diagonal bracing, and first-class foundations.

3. Improperly built brick and stone structures. The brick walls which failed, either by being shaken down entirely or by shattering, were laid in lime mortar with few header courses, and generally had wooden frames with little or no bracing and no tie to the walls. Stone and brick masonry cracked diagonally in the form of an X. Hollow-tile partitions and masonry of brick or stone were similarly cracked, although this injury was small where Portland-cement mortar was used. Where the walls were laid with hard brick, with plenty of headers and in Portland-cement mortar, and were properly tied to the floor and roof members there was little, if any, damage. Chimneys collapsed most generally, breaking about halfway up, and destroyed in part at least the structures upon which they fell. While the evidence was by no means conclusive, it appeared to the writer that brick stacks of circular section proved more substantial than square ones. The stack of the Valencia street power plant, which was of eight-pointed star section, collapsed, the part which remained standing showing cracks at one of two opposite reentrant angles almost to the base (Pl. LIII, A). It is quite evident that brick stacks and similar tall structures built of brick or stone without reinforcement against flexure, or without being guyed, are unsuitable for use in countries liable to earthquake shock. They should be constructed either of steel, guyed, or, if self-supporting, of steel or reinforced concrete. (See also Pl. XIII, A.)

4. Insufficiently braced and loosely constructed steel structures. In structures which were deficient in diagonal bracing the effect of the earthquake was localized in the piers between openings and curtain walls in characteristic X cracks. In tall structures like the Call Building, the tower of the Union Ferry Building, and others, the diagonal bracing that had been installed proved insufficient, and the diagonals at about the middle distance between the top and base were strained beyond the elastic limit of the material, acquiring a permanent set, which was indicated by a slight buckling. It is assumed that the effect of earthquake shock on diagonal bracing is equivalent to a heavy wind pressure, variously estimated at 30 to 50 pounds

per square inch. The writer believes that the higher figure should be used, because the essential in satisfactory earthquake-resistant design is rigidity, whereby the structure moves as a unit. Unless there should be earthquakes of greater severity than the one under discussion, no fear need be felt for tall buildings. It has been fully demonstrated that a steel frame well braced diagonally upon an adequate foundation successfully meets the earthquake requirements; not even the masonry being injured to any great extent.

Concrete, especially reenforced concrete, because of its great adhesive strength and reenforcing metal, proved more satisfactory than any other material. Its solid monolithic structure produces a successful earthquake-resisting material, inasmuch as it moves as a unit; moreover, it offers a maximum resistance to fire. The great concrete dam of the Crystal Springs Lake at San Mateo (Pl. XI, *B*) gave abundant proof of the substantial qualities of concrete in a mass, for although it lies within a few hundred yards of the fault, it suffered no damage. Solid concrete floors proved satisfactory, though concrete in San Francisco was of a very poor quality, and flimsy concrete stiffened with light metal passed as reenforced concrete. Cinder concrete was used extensively for floors and elsewhere, and was of a very inferior grade. Much of it was high in sulphides, which had a deleterious effect on the embedded material, especially in floors where slight cracks permitted air and moisture to come in contact with these sulphides and the metal. For a proper earthquake-proof structure, everything—the design, the materials used, and the workmanship—must be first-class. Most of the failures resulted from bad design, poor workmanship, and poor materials. If reen-



The following requirements should be adhered to in structures for earthquake countries:

1. Location on or near the fault should be avoided.
2. Foundations and superstructures should be so built that they will move as a unit.
3. Wooden structures should be rather heavily framed, with continuity in the vertical members, adequate diagonal bracing, and substantial foundations.
4. Steel structures should rest upon an adequate foundation and be thoroughly braced diagonally. This feature is a most important one, as rigidity is absolutely essential.
5. Brickwork and stonework should be thoroughly bonded with full header courses laid in Portland-cement mortar.
6. Masonry should be thoroughly tied to the steel or other framing members.
7. Buildings should have no unnecessary material in their superstructures, and heavy ornamentation should be omitted.
8. Flimsy floors and partitions should be avoided; reenforced concrete is an excellent material for both.

Professor Omori, chairman of the Japanese earthquake commission, and other earthquake authorities, have stated that great earthquakes are followed by a settled condition in the earth's surface and that there is an interval of fifty or one hundred years during which no earthquakes occur. The general fear which prevailed during the first days following the earthquake has been quieted by these assurances, which have also created a feeling of security that has led to a relaxation of the precautions necessary in the work of reconstruction. The lessons taught by the great calamities such as have befallen San Francisco, Baltimore, Chicago, and other cities are not regarded. It is very probable that the new San Francisco to rise on the ruins will be, to a large extent, a duplicate of the former city in defects of construction.

OBSTACLES TO RECONSTRUCTION OF SAN FRANCISCO.

The actual loss by fire in San Francisco was much greater than in the Baltimore fire, for the reason that many insurance companies have taken advantage of the earthquake clause in the policies and failed to pay their claims, while others without the requisite funds were unable to pay the large claims in full. This failure to pay a very considerable percentage of the fire losses and the delay in adjusting them have proved serious setbacks in the progress of reconstruction.

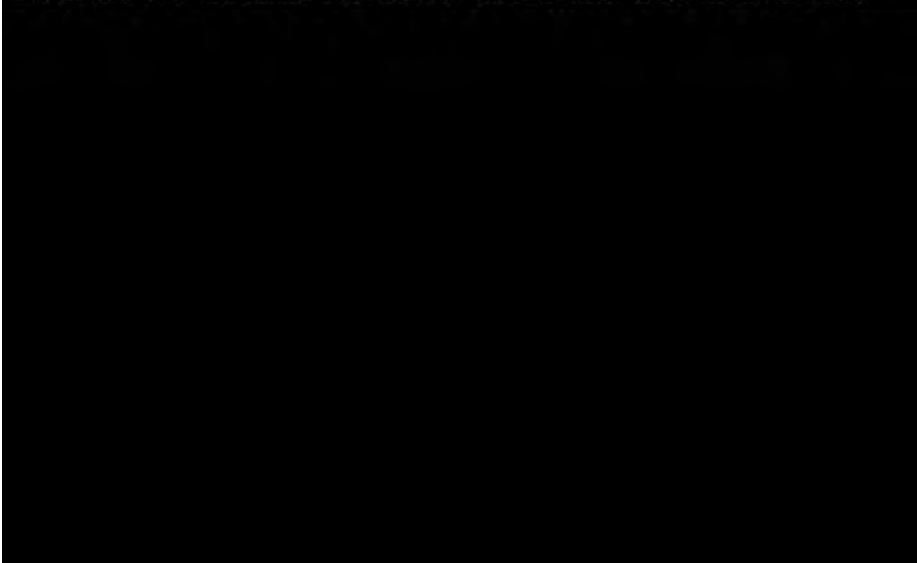
The new building code is also operating against the best interests of the city. The arbitrary classification of buildings based on the

type of construction is one which will result in more harm than good. Those interested in its preparation directed their attention principally to office and other large buildings, apparently not realizing that the greater proportion of reconstruction will consist of small three or four story buildings. The fact that a structure is built of steel and fireproofed does not make it superior to those representing other types of construction, for poor materials and workmanship may produce inferior quality, whatever the type.

The proposed code discriminates against reenforced-concrete buildings in designating them as class B structures. While not intentional, this conveys the impression that such buildings are next in order of superiority to structures of class A. Class A should embrace buildings so well designed and constructed of such first-class materials that they afford the maximum resistance to fire, and should represent the best method of fireproof construction regardless of type.

That there was only one reenforced-concrete building of the modern type in San Francisco was due in part to the opposition of the labor unions. The exorbitant demands for wages, coupled with the high cost of materials, have proved a serious handicap. The cost of all construction work is excessive at the present time, and business interests will suffer from the shrinkage in value which will follow the fall in price of labor and materials. This policy of the labor organizations is materially interfering with and checking the work of reconstruction.

In addition to these labor difficulties, the questions of widening and extending old streets and opening new ones, for the purpose of carrying out the plans for the new and greater city, are still unde-



most of the inhabitants were in houses, 90 per cent of which were of frame. Structures of this type withstood the earthquake shock particularly well, which accounts for the minimum loss of life. Had the earthquake occurred four or five hours later, when the people were performing their daily tasks, in offices, schools, etc., or on the streets, the loss of life must have been very great. The writer saw a view of a drove of cattle buried under the ruins of a fallen wall while passing through Mission street, which graphically told the story of what might have occurred had the shock come later in the day. Although the loss of life was small, more than 200,000 people were rendered homeless and dependent on the authorities for even the necessities of life.

In three days the tremendous area of more than 2,593 acres was burned, destroying entirely 490 city blocks and in part 32 blocks. (See Pls. LIV-LVII.) Of this area, 314 acres constituted the congested district, on which there was \$250,000,000 insurance, probably representing a value of at least \$500,000,000.

In the Baltimore fire (February, 1904) 1,343 buildings were destroyed, having an assessed value of \$12,908,300. In two years these burned buildings were replaced by 570 buildings, whose assessed value is \$20,000,000. These new buildings are larger than the old, and the widening of the streets has eliminated 700 building lots. It is expected that when the reconstruction within the burned district is complete there will be fewer than 800 buildings, of which the assessed value will be fully \$25,000,000. It is therefore quite reasonable to suppose that the assessed value of the reconstructed San Francisco will be at least double that at the time of the catastrophe.

THE EFFECTS OF THE EARTHQUAKE AND FIRE ON BUILDINGS, ENGINEERING STRUCTURES, AND STRUCTURAL MATERIALS.

By JOHN STEPHEN SEWELL.

INTRODUCTION.

SCOPE OF THE INVESTIGATION.

The following pages contain the matter of a report dated July 5, 1906, to Brig. Gen. Alexander Mackenzie, Chief of Engineers, United States Army, of an inspection made by me of the ruins of San Francisco, in accordance with Special Orders No. 97, dated War Department, Washington, April 23, 1906.

I arrived in San Francisco on the morning of May 8, 1906, and remained until the night of May 19. My orders directed me to investigate the effect of the fire and earthquake on buildings and engineering structures in the territory affected by the earthquake, and authorized me to visit such points in addition to San Francisco as it might be necessary to observe. As soon as possible after my arrival, I



personal examination would consume a great deal of time. It also disclosed the fact that an examination was in process by competent engineers, and Major McKinstry undertook to get for me a report of the results of this examination. As a matter of fact, I have been allowed to see a copy of such a report made by Charles D. Marx and Charles B. Wing, which the authors prefer not to have published as yet. However, certain essential facts as to the condition of dams, conduits, etc. (see Pls. IX; X, A; XI, B), are taken from it and embodied further on in my own report; although the photographs and certain other features of the report itself, which seem to be peculiarly the property of its authors, are not submitted herewith. In view of the fact that the results of the examination of the waterworks were promised to me, it seemed superfluous for me to visit the dams and conduits, except as a matter of personal interest, and as my time was very short, I decided not to do so.

The light-houses and fortifications are in charge of competent officers, whose duty it is to report the nature and extent of the damage done to them by the earthquake. As an inspection of the light-houses would have involved a great deal of time, I decided not to attempt to visit them, and made only a superficial examination of the fortifications.

As my own experience has been mainly in the line of fireproof buildings, however, I made a very careful inspection of the ruins of San Francisco itself, and also visited Oakland and Palo Alto, with a view to inspecting damaged buildings at those points. I found, as a result of those trips and by inquiry among competent witnesses, that, with one exception, there was no type of building in the affected district which was not well represented among the buildings of San Francisco. The exception was the concrete work at Leland Stanford Junior University, near Palo Alto, to which specific reference is made on page 113. The greater part of my time, for the reasons above outlined, was spent within the limits of San Francisco itself, and much of it within what had been the congested district of the city.

ACKNOWLEDGMENTS.

Acknowledgment is due to Capt. M. L. Walker, Corps of Engineers, commanding officer at Fort Mason, who not only entertained me at his quarters during my stay in San Francisco, but rendered very material assistance in the way of transportation when needed, and especially in placing at my disposal the services of Private William H. Hughes, of the First Battalion of Engineers, a very efficient photographer, who accompanied me and took such views as seemed desirable for the purposes of my report. I was also much indebted to Maj. C. H. McKinstry, Corps of Engineers, who gave me much

valuable information that made it possible to avoid useless expenditure of time, and who was also of great service in procuring for me the necessary permits from the local civil authorities.

EXTRACTS FROM THE REPORT OF A COMMITTEE OF THE NATIONAL BOARD OF FIRE UNDERWRITERS ON SAN FRANCISCO CONDITIONS.

San Francisco before the earthquake and fire consisted mainly of frame and brick buildings of ordinary construction. A few adobe buildings still remain, but there were not many of these. There were about 45 so-called fireproof buildings in the city, and a small number of so-called slow-burning buildings, modeled more or less loosely along the lines of the New England mills. A fair idea of the general nature of the city, so far as buildings are concerned, is given in the following quotations from a report on San Francisco issued by the committee of twenty of the National Board of Fire Underwriters in October, 1905:

CONFLAGRATION HAZARD.

Potential.—In view of the excessively large areas, great heights, numerous unprotected openings, general absence of fire breaks and stops, highly combustible nature of the buildings, many of which have sheathed walls and ceilings, frequency of light wells, and the presence of interspersed frame buildings, the potential hazard is very severe.

Probability feature.—The above features, combined with the almost total lack of sprinklers, and absence of modern protective devices generally, numerous and mutually aggravating conflagration breeders, high winds and comparatively narrow streets, make the probability feature alarmingly severe.

Summary.—While two of the five sections into which the congested-value



In addition to the frame, ordinary joisted brick, so-called fireproof, and mill buildings, there were in San Francisco four buildings of a monumental type, so far as weight of construction was concerned. These were the new city hall (Pl. XXXI), the new post-office building (Pls. XLIII and XLIV), the United States mint (Pl. XXXVIII), and the appraisers' stores, or custom-house (Pl. XXVIII, A). The few mill buildings which existed were not of a standard type, according to the report of the National Board of Fire Underwriters. The fireproof buildings had been erected in accordance with the building laws of San Francisco, which provided for three principal types of commercial buildings, known as class A, class B, and class C.

The general requirements for buildings of these classes and for mill buildings are as follows:

BUILDINGS IN FIRE LIMITS.

SECTION 96. Every building hereafter erected within the fire limits shall be constructed in accordance with the requirements of this ordinance for the construction of buildings of either class A, class B, or class C.

BUILDINGS OF CLASSES A, B, AND C.

SECTION 97. Class A, termed "fireproof," or "skeleton construction," shall include all buildings wherein all external and internal loads and strains are transmitted from the top of the building to the foundation by skeleton or framework of steel, and the beams or girders of which are riveted to each other at their respective juncture joints. A building of this class must be constructed of noninflammable material throughout, and all interior constructive metal work, with the exception of the framing for elevators and staircases, shall be protected from fire by brick or terra cotta at least 1½ inches thick, or by plastering three-fourths of an inch thick applied to metal lath. The face of the plastering shall be 1½ inches from the metal. Wood may be used only for window and door frames, sashes, standing finish, hand rails for stairs, and for the upper and under floors and their necessary sleepers. Wood may also be used for isolated furring blocks, but this class shall not permit the use of laths or furrings of wood.

Class B. A building of this class shall be constructed with all its exterior walls and piers of masonry, or of masonry and steel, and all exterior surfaces other than masonry shall be covered with noninflammable materials. All partitions, furred walls, or other plastered surfaces throughout shall be metal lathed. All interior metal work shall be protected as in class A, and in addition the floor and ceiling joists, posts, roof boards, and partitions may be of wood in such places as does not violate the requirements of any section or clause of this ordinance.

Class C. A building of this class shall be constructed the same as class B in every respect, except as to the requirements for interior lathing.

SECTION 98. Limit of height of buildings of classes A, B, and C:

	Feet.
Class A, limit of height.....	220
Class B, limit of height.....	100
Class C, limit of height.....	82

(As amended by Ordinance 1297.)

SLOW-BURNING OR "MILL" CONSTRUCTION.

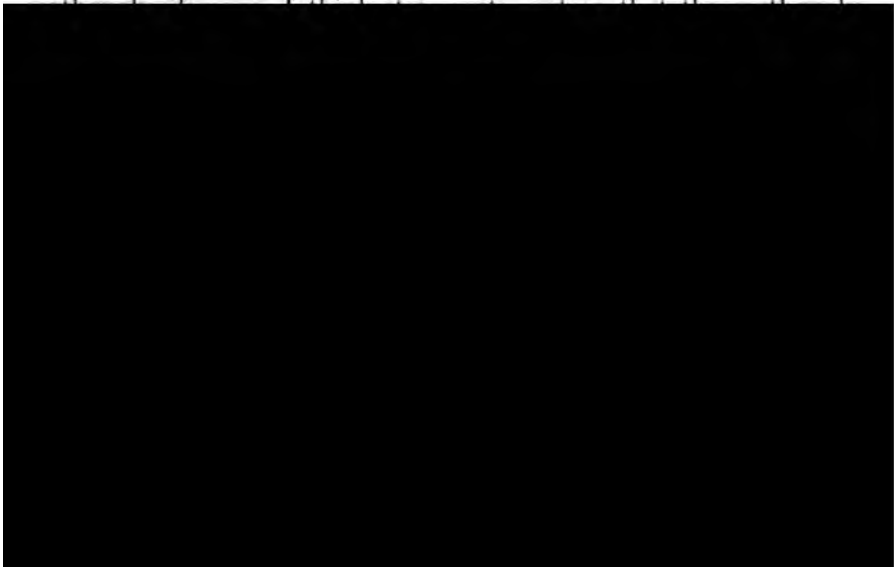
SECTION 99. A building of the slow-burning or "mill" construction type is a building whose outside walls are built of masonry, concentrated in piers or buttresses, between which is a thin wall containing the door and window openings, and whose floors and roof are constructed of heavy timbers, covered with plank of a suitable thickness; the girders being supported between the walls by posts.

SOME FEATURES OF THE EARTHQUAKE AND FIRE.

AMOUNT OF DESTRUCTION DUE TO THE EARTHQUAKE AND FIRE,
RESPECTIVELY.

Within the burned area all frame buildings and practically all buildings with timber floors were totally destroyed, with all their contents. This classification includes mill buildings and those of every other type in which the floor construction is combustible. Practically all the so-called fireproof buildings were gutted, and their contents were a total loss. The average loss on the buildings of class A was, in my judgment, considerably in excess of the average loss on the "fireproof" buildings in Baltimore. This statement can not be made with absolute positiveness, however, in the absence of a detailed estimate of the cost of repairing each building, which I had not time to make. I am quite sure, however, that the damage in San Francisco was greater than it was in Baltimore.

From what was left of the ruins themselves, and from the testimony of competent observers, including engineer officers who were ordered into the business district of San Francisco immediately after the earthquake and before the fire had destroyed the evidences of



to the breaking of the conduits and mains, left the fire practically in control of the situation. Some attempts were made to stop its progress with dynamite, but from what evidence I was able to obtain I doubt very much whether a great deal was accomplished by this means. It is probable that at one or two points where the fire had become much less fierce its progress was entirely stopped by the use of dynamite, but even this much is not certain. I am personally of the opinion that dynamite might be used so as to check the progress of a conflagration, but it has never been properly applied to that purpose as yet. It seems probable that if a strip of property, a whole city block in depth, extending across the entire front of the fire, were selected sufficiently far in advance to enable it to be completely razed by dynamite before the fire reached it it would prove an effectual barrier, especially if there were water available to keep the ruins thoroughly wet. In the absence of the water the only way to make sure of the result would be to have an enormous number of men ready, as soon as the buildings were demolished, to move the débris to the side nearest to the approaching fire. It is probable that the ruins would be set on fire by the dynamite itself, but with a sufficient number of men, properly handled, the amount of combustible matter along the side next to unburned property might be so materially reduced that the fire would not be able to cross the gap. I rather think that unless such heroic measures are applied the use of dynamite is just as likely to do harm as good in resisting the advance of a conflagration. It will readily occur to anyone at all familiar with such things that to get together the requisite number of men and properly direct their work would require full military control of the situation; otherwise the measures described, while not impossible, would hardly be practicable.

One or two attempts were made, apparently with not a great deal of judgment, to dynamite steel-frame buildings that were on fire. I understand that the explosive was simply placed in the basement loose, practically without any tamping, and detonated. The only result was to knock a few basement columns off their foundations and bring down a portion of the floor construction above. I doubt whether any good results could be obtained by trying to dynamite a steel-frame building as a means of stopping the advance of a fire. If, in a strip of property such as that described above, any steel-frame buildings exist, especially if the frames are protected with any sort of fireproofing, it is probable that more good would result from allowing them to stand, while dynamiting their combustible neighbors.

It would be practically impossible in the time available to demolish a steel frame so completely that all of the combustible débris could be removed. It would burn more and more.

trously after dynamiting than if the building were left intact. A good plan in such a case would be to remove all the combustible contents of the building before the fire reached it, throwing them out, if no other course were open, on the side next to the advancing conflagration. Under such circumstances the average fireproof building, while it might be ruined itself, would probably act as a barrier to the spread of the flames beyond it, although, of course, it could not prevent the fire from working around the sides if neighboring combustible buildings were not removed.

A certain amount of damage in addition to that caused by the fire and earthquake was done in San Francisco by the dynamite used to blow down dangerous walls. More specific data on this point are presented in the detailed descriptions.

TEMPERATURE OF THE BALTIMORE AND SAN FRANCISCO FIRES.

The apparently more complete destruction by fire at San Francisco than at Baltimore immediately raises questions as to the probable temperature of the San Francisco fire. I noted everything coming under my observation which would seem to give an idea as to the probable temperature prevailing, and I am personally of the opinion that the San Francisco fire was appreciably hotter than that at Baltimore. Thus, in places which had been occupied by hardware stores I saw kegs of nails with the wood all burned away, but with the nails still standing up in a compact mass, retaining the shape of the keg, owing to the fact that they had been partially welded together. In other places kegs of nails which had evidently fallen at least one story, and possibly several stories, into the basement of an adjoining

sheet metal, though they showed no evidence of melting, had been almost completely burned up, so that they were full of holes, and the metal itself presented the same appearance as iron that had been burned in a blacksmith's forge. In the warehouse of the Waterhouse & Lester Company, on Howard street, some racks of steel bars were precipitated into the basement when the building collapsed. These bars were partially welded together by heat. (See also Pl. LI, *B*.) In the ruins of glassware and china stores the glass, as a rule, was completely melted, and many articles of porcelain ware had become softened and distorted in all manner of shapes, indicating a high temperature, as porcelain is made of very refractory material.

All things considered, I am inclined to think that temperatures considerably in excess of 2,000° F. were not at all uncommon in the San Francisco fire, although there were manifestly, in the burned area, places where no such temperature was reached. Very few office buildings were subjected to such intense heat, except here and there in individual rooms, where there was evidence of the storage of records or other combustible matter in large quantities; but the department stores, dry goods stores, and other buildings of mercantile occupancy evidently suffered from temperatures at least as high as 2,000° F. In mercantile buildings these high temperatures seemed to be the rule and not the exception.

EARTHQUAKE- AND FIRE-RESISTING QUALITIES OF STRUCTURES AND STRUCTURAL MATERIALS.

EFFECT OF FIRE ON GOVERNMENT AND "CLASS A" COMMERCIAL BUILDINGS.

So far as resistance to the fire is concerned, the only buildings that presented anything of interest were naturally the monumental public buildings and the commercial fireproof buildings of the better class; that is, practically of class A. The fire did not succeed in entering the mint nor the appraisers' stores. It got into the upper story of the new post-office building at one corner, and cleaned out a court room and its adjoining offices; but it was held at this point, and the post-office building itself was not involved in a fierce conflagration such as that which ruined many of the commercial buildings. The fire got into the new city hall, and succeeded in wrecking the portion which was not ruined by the earthquake.

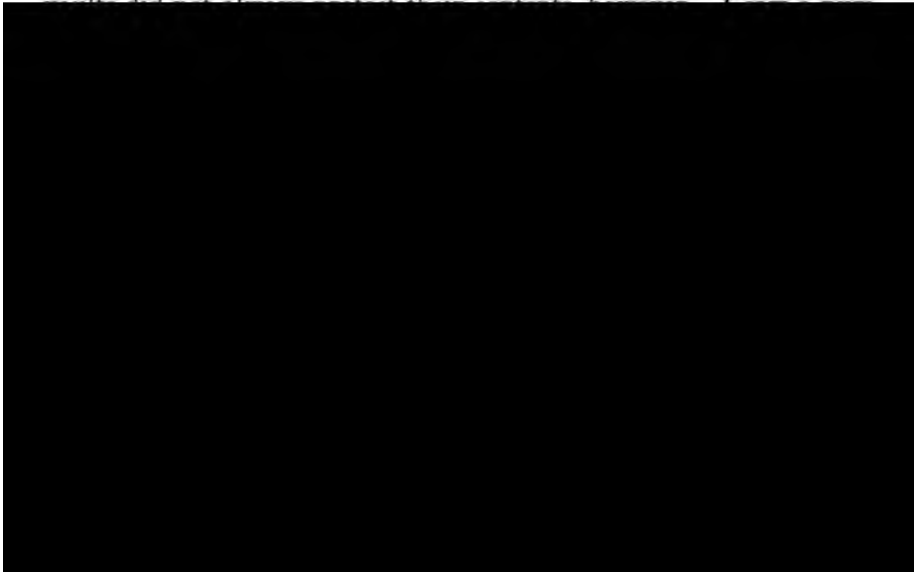
VAULTS AND SAFES.

In many of the office buildings in San Francisco suites of offices were equipped with vaults, some of which were fairly capacious and provided with doors of more or less efficient appearance, a number of them having the ordinary vestibule, with both inner and outer doors. For partitions of the building consisted of metal

furring, lathing, and plaster, the walls of the vaults were likewise of these materials. Where the interior partitions consisted of hollow tile, the walls of the vaults were of hollow tile also. Although I examined a great many, I did not see a single vault partitioned off either with metal lathing and plaster or with hollow tiles that preserved its contents. I was informed by some gentlemen, who were apparently connected with the Spring Valley Water Company, that on the top floor of their building a vault walled off with hollow tiles had protected its contents, but that the corner of the building in which it was situated had not been completely gutted, so that the vault did not receive a severe test.

In the Baltimore fire there were a number of vaults walled off with hollow tiles, and all that I happened to see during my inspection of the ruins in Baltimore had failed. The same thing was in evidence everywhere in San Francisco, and it is my opinion that this result could have been predicted with absolute certainty at the time these vaults were built, from data then available. To all external appearances, no doubt, the vaults looked like secure places in which to keep valuables; as a matter of fact, they were the flimsiest kind of shells, not capable of resisting any sort of determined attack from either fire or burglars. The tenant would have been better off without the vault, for in that case he would probably have carried his papers to some other point where they would have had a better chance to escape the fire.

The only vaults I saw that came through a really fierce fire without damage were those built of brickwork (Pl. LII, A). Even these



been prevented with an adequate number of bolts I do not know, but in an important vault it would seem worth while to have the outer door at least filled in the same manner as the door of a fireproof safe. If it were built in this way it would probably not warp—at least not enough to let the fire in.

To judge from the safes which I saw opened, very nearly three-fourths of the safes in the San Francisco fire failed to protect their contents (Pl. LII, *B*), and as a result the loss of valuable papers and records must have been very extensive.

BEHAVIOR OF STRUCTURAL MEMBERS AND MATERIALS.

The commercial fireproof buildings in San Francisco, in my judgment, suffered considerably more damage than corresponding buildings in the Baltimore conflagration. In the San Francisco fire, for the first time, the collapse of protected steel frames, due to the destruction of the fireproof covering at a comparatively early stage in the fire, was a matter of common occurrence. Practically all of the floor construction in fireproof buildings in San Francisco consisted either of hollow terra-cotta flat arches or of reenforced-concrete slabs, carried on steel floor beams. In a few buildings steel columns and girders were used, with reenforced-concrete beams and slabs covering the space between the girders. Steel girders were more generally protected with metal lathing and plaster, or with solid concrete filling, than with anything else, but terra-cotta covering was also used to a considerable extent. The lower flanges of beams were in some buildings unprotected; in others they were covered with metal lathing and plaster; and in still others (a rather general practice), there was a ceiling composed of light furring angles and metal lathing, fastened below the floor construction and plastered. Most of the steel beams and girders in the floor construction had no other protection for their lower flanges than this furred ceiling, even where the webs were protected by a solid concrete filling.

Columns were generally protected in one of three different ways, as follows:

1. With hollow tiles adapted to either a circular or square section, the webs being about five-eighths of an inch thick, and the total thickness of the tile, including webs and hollow space within, being about $2\frac{1}{2}$ or 3 inches. The tiles were from 12 to 18 inches in length and about 12 or 15 inches wide.

2. With metal lathing and plaster surrounding the column, so as to leave an air space of about 1 or $1\frac{1}{2}$ inches.

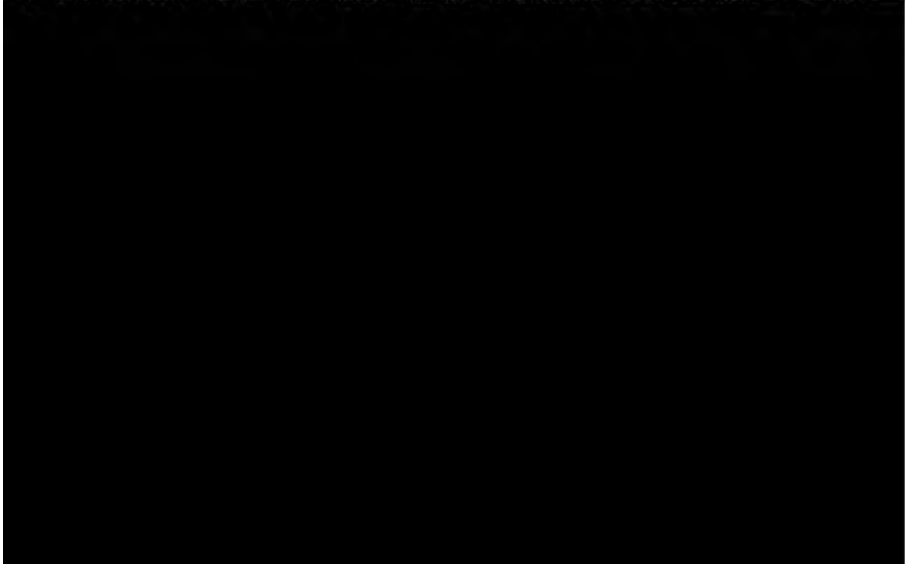
3. With a solid covering of concrete from 2 to 4 inches thick.

In addition to this protection the columns in the walls were generally covered with 4 inches of brickwork, and in one building there was of metal lathing around isolated columns,

inner covering having one coat of plaster applied and the outer covering having the full two or three coats required for the finishing, as the case might be.

In a general way, practically none of the column protection in San Francisco, except the 4-inch brick covering, was adequate. The coverings of terra cotta and of metal lathing and plaster failed absolutely. Although there were a great many individual columns protected with other coverings which suffered only small damage, the number in which the protection completely failed was so great that the statement is entirely justified that practically all the coverings were wholly inadequate to resist any real fire test. The wall columns covered with 4 inches of brickwork were, except in one building, fairly well protected, so far as I was able to determine. None of the columns covered with cinder concrete suffered any serious damage, but there were not many columns protected in this way. Of the three buildings in which I particularly noticed such covering, two had evidently not experienced any great heat. In the third a column covered with 4 inches of cinder concrete had undoubtedly been subjected to a heat that was very intense. The concrete covering was seriously damaged; the column, however, had not suffered. This case is described on page 79.

Interior partitions in San Francisco were built almost entirely of hollow tiles similar to those used for making square coverings on columns, or else of light metal studs covered with metal lathing and plaster. A few were built of brickwork. In a general way it may be said that practically all the interior partitions that were not built of brickwork were a total loss, being absolutely inadequate. In my



are not fireproof, and a very hot fire will invariably destroy them, notwithstanding the fact that they are made of noncombustible material. I had rather expected to find that some damage had been done by the earthquake to floors made of hollow tiles or brick arches. That no such damage occurred was a matter of some surprise, and indicates that the vertical component of the undulation was not very great. It is probable that the earthquake caused some cracks to appear in the floors, but I did not see any which could with certainty be ascribed to this cause. It was also a matter of some surprise that some of the partitions were not shaken down by the earthquake, considering the ease with which the fire destroyed them.

So far as fire damage was concerned, the floor systems in San Francisco stood better than any other portion of the fireproof buildings, although they did not stand very well, at that. The lower webs came off from the hollow-tile floor arches in the same way that they did at Baltimore, but to a very much greater extent. The cinder-concrete floor slabs in many buildings were protected for a time by the furred ceilings previously described. Where the ceilings failed at an early stage, or where there had been no such ceilings, the damage to the concrete floor slabs was very apparent. The concrete was dehydrated to a certain extent on its lower surface, and in many of the slabs the reenforcement had become so hot that there was a permanent deflection of greater or less extent, accompanied by cracks on the lower side in the middle of the span.

Just how much damage was done by the fire to cinder-concrete slabs was a little difficult to determine, for the reason that most of the cinder concrete used in San Francisco was evidently a very inferior article in the first place. There was no doubt in my mind, however, that the concrete near surfaces which had been exposed to the fire showed deterioration, as compared with that which had not been exposed to the fire, although it was all so poor that there was not much room for difference in quality. I saw reenforced-concrete floor slabs, some of cinders and some of stone, which were on the point of collapse from heat alone, although they had not quite let go.

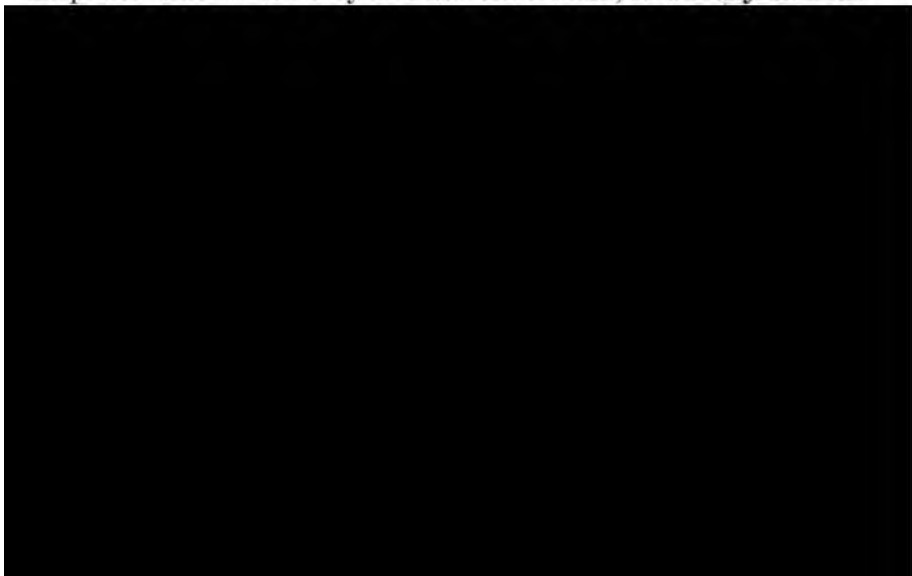
I also saw a number of terra-cotta floor arches which had totally collapsed. Some of these showed evidence of damage by masses falling from above, but in others the collapse seemed to have been due to heat alone.

Girder and beam protection was a little more efficient than the column coverings, but it was not adequate. Its weakness was not fully developed, because, in many places where the necessary heat existed, the columns failed first and let down the floors, so that it was not possible to say how much of the damage to the floor members was due to heat alone. In a general way, however, it may be said that girder coverings of metal lath and plaster were wholly inade-

quate, those of hollow tiles suffered serious damage, and those of solid concrete failed a little more commonly than they should, although they were the best of all. Many girders that had been covered with metal lath and plaster were badly warped and deflected, and some wholly collapsed, from the heat alone. Many beams were seriously deflected from the heating of exposed lower flanges.

I was not able to learn that any serious damage had been done to column coverings by the earthquake. In some buildings columns which had not been exposed to much heat happened to be standing with their covering absolutely intact, while another column not far away in the same story of the building and evidently subjected to an intense heat had not only lost its covering, but had itself been practically destroyed by the fire. In no such case was I able to discover any evidence of earthquake damage in the covering that was intact, and there was nothing to indicate that one column might have had its covering damaged by the earthquake, while its neighbor escaped. More detailed information relative to fire damage is presented in the discussion of the individual buildings (pp. 76-108).

The earthquake did a great deal of damage, which could easily be differentiated from that due to the fire. As a rule brickwork in San Francisco was laid in lime mortar or in lime mortar gaged with a small amount of Portland cement. Wherever such masonry was subjected to serious earthquake shocks it was very badly shattered. Much of it came down in the ruins, and much of that which remained in place was reduced to a loose pile, without any adhesion between the mortar and the bricks. The bricks in general were more or less misplaced even where they did not come down, and many of them



In steel-frame buildings put up in the ordinary way, without any special bracing, most of the earthquake effect was localized in piers between windows, as if a horizontal force had been applied to the floor above, tending to slide it with reference to the floor below. As this effect occurred in both directions, the piers referred to were generally marked with X-shaped cracks, and in addition the masonry was apt to be very much shattered. There seemed to be no general rule as to the place where this shattering effect occurred. In some buildings the piers in the one or two stories near the middle of the height of the building seemed to have suffered the most; in others, the piers nearer to the roof. One tall building, which extended far above its neighbors, was seriously damaged in practically every story above the neighboring buildings.

It was apparent that in some buildings the shock was so severe that probably no structure, however well built, could have withstood it absolutely without damage. It was equally apparent, however, that such great exhibitions of energy were confined to small areas, and that it would be possible to put up buildings in San Francisco which would come through a similar earthquake with very little damage except to individual buildings here and there.

Hollow-tile work seemed to be badly shattered by the earthquake in a great many places. Well-executed stone masonry, as a rule, stood better than brickwork. Brickwork built with good hard bricks, laid in Portland-cement mortar, stood better than that built with inferior bricks or inferior mortar.

Of all the structures which were manifestly exposed to severe shock the concrete buildings at Palo Alto stood best. It would seem to be a general rule that increased tensile strength, even in a brittle material, greatly increased the resistance to earthquake shock. The height above the ground at which the damage was greatest appeared to be largely a function of the distribution of mass in the structure itself, combined with the distribution of the bracing. If the base of a tall steel-frame building were subjected to a vibration tending to tilt it, manifestly some time would be required to set the upper part of the building in motion. As the vibration evidently occurred in both directions, there would be a reversal of motion before the upper part of the building had responded to the first impulse. Under these circumstances there would be established somewhere a center of oscillation, where very severe stresses, due to the acceleration of the superincumbent mass, would be largely concentrated.

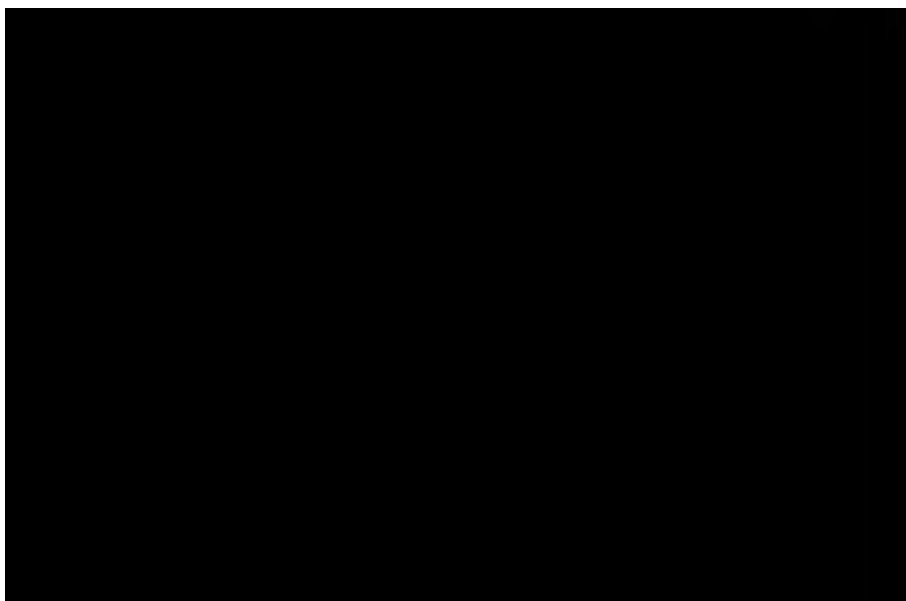
It might have been supposed that most of the destructive effect of such action would be manifested at the joints in a steel-frame building; but around the joints are concentrated the ends of the floor beams and girders, together with the floor construction, and at the only portion of the walls which is per-

fectly solid. The shafts of the columns at about midstory height are therefore less efficiently braced than the portions on a level with the floors. Moreover, it is probable that the play in the connections of the steel work at the floor level would permit a little motion here without any damage, provided, in the meantime, the bracing at mid-story, due to the masonry, is sufficient to preserve the structure from collapse; thus the connections would escape without material damage. As a matter of fact, some such action seems to have taken place. There was very little damage at the points where the steel work was fastened together; at least, very little that was apparent.

The failure of the masonry in the piers seems to have prevented the columns from being broken across in the middle or permanently deflected. It is an interesting speculation how near some of the unbraced steel-frame buildings were to total collapse under the stresses above described. In my judgment many of them were a little too near for safety. I saw a number of field bolts or rivets that I thought had probably been sheared by the earthquake, but as to most of them I was not sure that they had ever been in place. In one or two instances, however, the earthquake effect was indisputable.

As it is very difficult to discuss the earthquake effect in a general way, however, it will be taken up further in connection with the sub-joined detailed description of the effect of the earthquake and fire on individual buildings in San Francisco.

BEHAVIOR OF INDIVIDUAL STRUCTURES.



XXV, A, shows the corner of the building and the subsidence of the street at this point. The inlet at the corner indicates the original level of the street. There was a vault under the Market street sidewalk, immediately behind the wall at the curb line. The basement floor in this vault was of concrete and had a total thickness of 7 or 8 inches. The earthquake caused the earth to bulge up in the portion of the basement under the sidewalk, rupturing the concrete floor and turning it up on its edge, so that where there had previously been a clear headroom of $7\frac{1}{2}$ feet the highest point of the bulge was within $3\frac{1}{2}$ feet of the beams carrying the sidewalk. The columns were of steel, protected with expanded metal and plaster. The girders were of steel and the space between them was spanned by reinforced-concrete construction. The reinforced-concrete beams were formed on the lower edge by a curved piece of flat steel (Pl. XXIX, B). The concrete floor construction was damaged by the heat to such an extent that a heavy load of sheet iron on the third floor broke through, though it did not fall through bodily. The expanded metal that was used for reinforcing the slabs from rib to rib evidently got hot and was ruptured at this point.

The cinder concrete used in the floor construction of this building was badly damaged by the heat, although the heat could not have been very intense, as otherwise the ribs, with their exposed metal reinforcement, must have failed. Moreover, the girders did not have their lower flanges protected, yet they remained straight. A great many of the ribs, however, were deflected very considerably, but, owing to the fact that they were curved to begin with, this deflection, due to the fire damage, was not very apparent. The columns themselves were practically uninjured, although the column covering was severely damaged and will probably have to be totally renewed. There were some terra-cotta partitions, terra-cotta furring, and furred ceilings in this building, all of which totally failed. The brick wall at the west side of the building exhibited some earthquake cracks, and at a number of places the brickwork spalled under the heat.

APPRAISERS' WAREHOUSE.

The appraisers' warehouse was a very heavy structure, built on the old-fashioned monumental plan. (Pl. XXVIII, A.) It was entirely of brickwork, with some stone trimmings, and the exterior brickwork was laid with full header courses. It was practically undamaged by the earthquake, the chimney even being left standing, and the fire did not get into it. It is probable that the shock at the site of this building was not so severe as it was at some other places, or the chimneys, at any rate, would have been thrown down. The building itself shows a very few slight cracks, which may have been due to

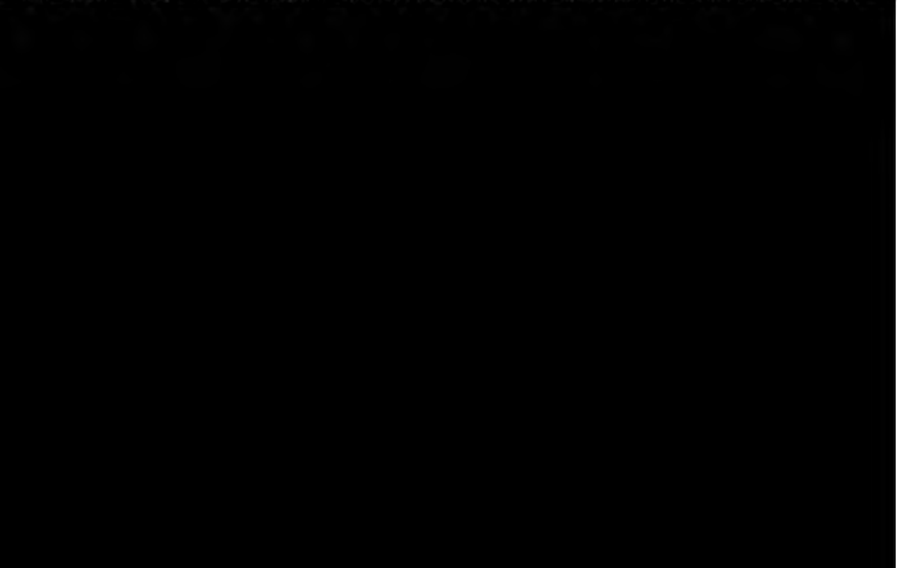
ordinary settling and not at all to earthquake. Mr. Roberts, the local representative of the Supervising Architect's Office, informed me that during the construction of the building there had been some unequal settling, so that one end was about $1\frac{1}{4}$ inches lower than the other, but that this settling had been at a uniform rate from one end to the other, so that it had caused practically no damage. On the interior there were many solid brick partitions, with some unprotected cast-iron columns. The floor construction was of steel or iron beams and segmental brick arches with a span of 3 to 6 feet.

It is worthy of note that immediately after the earthquake and fire three of the very few buildings in the burned district which were absolutely open and ready for business in every particular were the post-office, the mint, and the appraisers' warehouse. The massive construction used in these Government buildings would appear to have been a very good investment.

ARONSON BUILDING.

The ordinary ten-story steel-frame structure at the corner of Third and Mission streets known as the Aronson Building had terra-cotta column coverings and partitions and cinder-concrete floors, all of which were of the types described in this paper as common in commercial buildings. The building seems to have been occupied for light commercial purposes, and the fire test to which it was subjected was therefore somewhat more severe than that prevailing in office buildings.

A column in the basement was buckled, and two of the columns on the first floor were badly buckled near the ceiling, as shown in Pl.



think that in one or two other buildings in which there was a general collapse of the steel superstructure worse columns than this one could have been found under the débris. The débris was not cleared away while I was in San Francisco, so I had no opportunity to see the condition of many columns that had evidently failed.

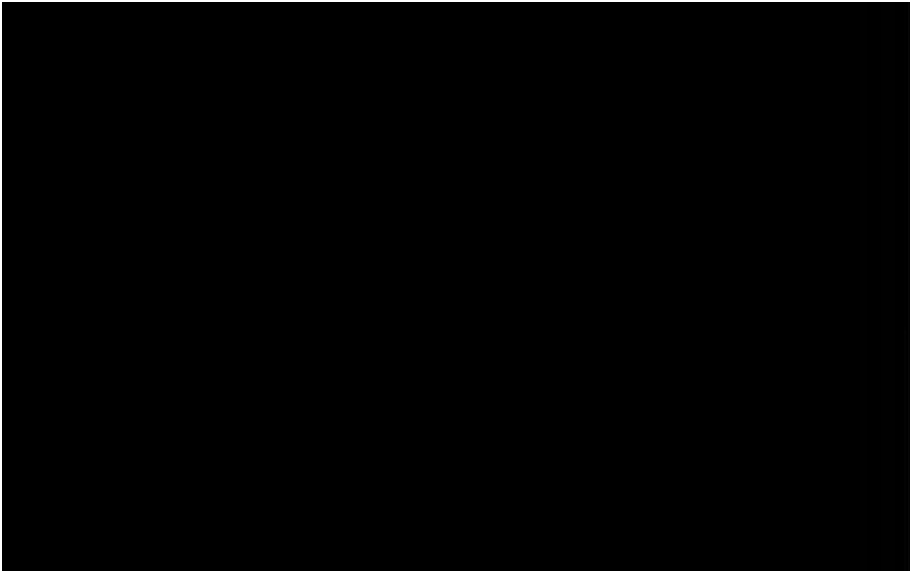
The basement of the Aronson Building was divided into several rooms by hollow-tile partitions. The room in which the buckled column was located had evidently contained an enormous amount of paper in some form or other, and the heat generated must have been very intense. The fire broke through the hollow-tile partition which separated this room from the adjacent one, but there was very little that was combustible in the latter, and the column standing there had its fireproof covering entirely intact. Examination showed that the work in this building was neither better nor worse than the average of similar work anywhere else in the San Francisco commercial buildings. A plain and inevitable inference is that wherever such work was practically undamaged the fire test was not at all severe.

In the same part of the basement as that in which the above-mentioned column was situated—that is, under the Third street wall of the building—there were two columns covered with cinder concrete. The concrete covering on one column made a very large and heavy pier; on the other it was about 4 inches thick. It was apparent that the heat in this front portion of the room was not quite as severe as it was farther back, where the buckled column was. Not only was there very much less evidence of fire in the way of ashes, etc., but the general indications pointed to a considerably lower temperature—although the heat at this point was very severe, nevertheless. The larger cinder-concrete pier was evidently damaged to some extent by the heat. The cement had apparently been dehydrated to a depth of one-fourth to three-eighths of an inch on the flat surface, and to a greater depth at the corners. The other pier showed more evidence of intense heat. It stood opposite the middle of the room, where there seems to have been the greatest accumulation of combustible matter. When I first saw this column the cinder concrete was dead and friable to a depth of nearly an inch. How much of this was due to original poor quality and how much to the action of the fire was difficult to determine, but fire damage was very evident. This pier showed on the surface a number of longitudinal cracks running from top to bottom, indicating that there had been a tendency for the concrete to fail and come off under the expansion stresses. At a later inspection a part of the concrete covering of this column had been knocked off, and it then became apparent that the cracks above referred to had extended entirely in to the surface of the column itself, and enough heat had got in to partly burn off the part of the inner edges of the cracks.

The stairways in this building had apparently been partitioned off by hollow-tile partitions, but these were totally wrecked, and the stairways were in such condition that it was only with great difficulty and by going on all fours that they could be used to reach the upper story. In the west wall of this building I saw the remains of a wire-glass window, with metal sash and frame, which had been practically destroyed by the heat—probably, however, as a result of a simultaneous attack by the fire from both sides. Wire glass seems to have done some good service in other buildings in San Francisco, although in the Merchants' Exchange, as in the Aronson Building, it failed completely, so that a constructing engineer, who had drawn his conclusions entirely from what he saw in the Merchants' Exchange, was disposed to condemn wire glass outright.

BULLOCK & JONES BUILDING.

The steel-frame Bullock & Jones Building was faced with ornamental terra cotta, with hollow-tile column covering and reenforced-concrete slabs which were haunched on the beams, the slab reenforcement apparently not being continuous over the tops of the beams. Some of the floor slabs collapsed, and the column coverings failed entirely. Two columns in the third story had buckled in the same way the columns buckled in the Aronson Building. This building was rather more flimsy even than the average commercial building, and the fire nearly brought it down. Pl. XXVI, A, is an interior view showing the buckled columns in the second story. It will be observed that pipes were run up inside of the column coverings.



tinuous over the top of the beam; otherwise the construction is nothing but an arch, and develops the thrust to be expected of an arch. Moreover, as a rule, tie-rods are omitted when reenforced-concrete floor slabs are used, and it was naturally to be expected that reenforced-concrete floor slabs of this type would collapse to some extent; the wonder is that they did not collapse to a greater extent in the Bullock & Jones Building. The fire damage to ornamental terracotta in this building was very conspicuous.

CALL BUILDING.

Of all the commercial buildings in San Francisco, by far the most interesting was that known as the Call (or Spreckels) Building, at the corner of Third and Market streets. This building is remarkable for the care and skill shown in the design of its steel work. It is a steel-frame building, all the walls, floors, partitions, etc., being carried on steel work. It has 15 main stories, in addition to the stories in the dome, or cupola, and rests upon a continuous foundation composed of concrete reenforced with steel beams. The building proper is about 75 feet square, but the foundation is about 90 by 110 feet, and was carried to a depth of about 25 feet below the sidewalk level. A fairly complete and satisfactory description of this building was published in the *Engineering Record* of April 9 and 16, 1898.

In the first four stories above the street the bents of the steel work adjacent to the four corners of the building on each side were braced with solid portal braces. In addition, eight interior bents were braced with diagonal tiebars from top to bottom. At all junctions of girders and beams with columns knee braces were used. The design of this steel work is well worthy of study by anyone interested in such structures. It is probably, on the whole, the best-designed piece of such work in the United States. Another remarkable thing about it is that the execution was apparently as good as the design. In a number of places where the fireproofing had come off the connections were exposed, and the workmanship here seemed to have been practically as good as it could well be made. I particularly noticed the column bearings, and they seemed to be absolutely close and true. Inaccurate column bearings in building work are so often seen that one is almost justified in saying that they are the rule rather than the exception; but in the Call Building such connections as were exposed to view had been put together with extreme accuracy.

The column covering in this building was of hollow tiles, about 3 inches thick, with very thin webs. Partitions were built of the same material. The floor construction was of reenforced cinder concrete. Some furred ceilings composed of wire lathing and light furring ~~stair man~~ also used. The outer walls were furred with 2-inch

hollow tiles. When I saw the building the column coverings and partitions throughout were either down or so badly shattered that nearly all of them would have to be taken down and rebuilt, and the furring had fallen from many of the outer walls. The chief engineer of the building stated that it was practically undamaged immediately after the earthquake, and that the fire which subsequently gained access did not damage it very much, but that a large part of the ruin of the partitions and column coverings was due to the concussions from the dynamite used in demolishing dangerous walls in the neighborhood.

The hollow-tile covering of the steel work came down pretty generally throughout the building. Whether or not this failure resulted from the fire, close examination of the steel work proved that the tile covering was totally inadequate, because in many places there had been heat enough to burn the paint entirely off the steel and to leave indications of high temperature on the metal itself. Photographs taken of the Call Building during the progress of the fire indicate that the fire was not very fierce, yet, in my judgment, some of the steel members were very close to serious damage as a result of it. So magnificent a piece of steel work deserved better fireproof covering than it had; but, as a matter of fact, the steel itself was observed to be fire blackened in many places. The furred ceilings in this building in general suffered so much damage that they should be taken down altogether. The marble finish throughout, while not absolutely destroyed, was so damaged as to be worthless. The reenforced-concrete floor slabs stood fairly well, but some of the



Market street by 8 inches and Third street by 10 inches. This indicates clearly that it is not safe to trust the eye in the matter of a building out of plumb, because when previously examined—not only once but several times—the Call Building presented the appearance of leaning away from Market street instead of toward it. In my judgment the deviation from the vertical in this building may have been due in whole or in part to the earthquake, but it is not at all impossible that it may have been built out of plumb. With the rigid type of connections used in the Call Building, strict mathematical accuracy of construction at all points would be essential to insure the exact perpendicularity of the building. As this accuracy is practically unattainable, it is ordinarily necessary to accept slight deviations from the plumb line and probably, in the majority of cases, a certain amount of torsion in the frame itself. So far as these deviations are kept within reasonable limits they make no serious difference, and the building is just as good for all practical purposes as if it were perfectly plumb and true.

On the whole, the foundations and steel frame of this building were admirably designed. The bracing of the steel work seems to have taken up the vibration due to the earthquake, so as to preserve the masonry of the outer walls. As long as there is no deflection sufficient to crack the masonry, there can be no doubt that the building is safe. It is a question whether other buildings which were not so well braced, and in which the piers between windows were badly shattered, were not dangerously near collapse, and it may well be doubted whether there is not serious damage to the steel work as it is. This matter could be determined only by uncovering the steel and making a detailed inspection.

The only safe plan in the construction of steel-frame buildings is the one followed in the Call Building—that is, to brace the steel work so that by itself it is able to resist the stresses due to the vibration. The engineer who designed the foundations and steel frame of this building may well be gratified at the admirable manner in which his structure fulfilled its purpose. Had the building been as well designed to resist fire as to resist earthquake, it is probable that the total damage would have been very much less than it was.

CHRONICLE BUILDINGS (OLD AND NEW).

The old Chronicle Building (Pl. XXX. *B*) seems to have been built in two parts—a west and an east wing. The west wing had protected cast-iron columns, rolled beams, and terra-cotta fireproofing. The interior structure had entirely collapsed, apparently from the heat. It was impossible, with the débris piled around it, to what the cause of the failure was, but it was probabl

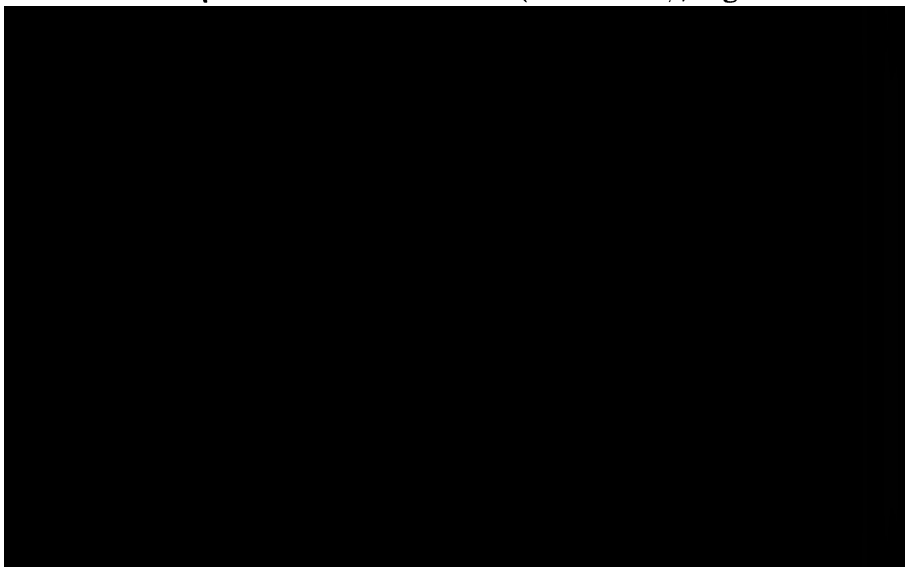
due to the buckling or rupture of a lower-story column by the fire. In the east wing of the old building the terra-cotta fireproofing had suffered, to a considerable extent, the typical damage which is described in connection with the Aronson Building (p. 78) and in the general discussion of the subject (p. 72). Many floor tiles had lost their lower webs.

The new Chronicle Building (also shown in Pl. XXX, *B*) was badly racked by the earthquake from the point where it rose above the neighboring buildings to the top. It seems to have been provided with knee braces tending to stiffen it in a direction parallel to the Kearney street front. In the first story, at any rate, there were some diagonal braces in the steel work of the north wall. The worst damage was to the masonry of the Kearney street front; the shattering of this masonry can be observed by a close inspection of Pl. XXX, *B*. This building was unfinished. It had hollow-tile fireproofing, including partitions. The burning out of the window trim and of whatever combustible matter may have been in the building, caused a good deal of damage to the hollow-tile floors, especially near the windows, where the lower webs came off almost completely.

The old Chronicle Building seems to have suffered very little from the earthquake, notwithstanding it must have acted as a buttress for the new building.

CITY HALL AND HALL OF RECORDS.

The new city hall in San Francisco (Pl. XXXI), together with



work by any means. I found a few places where joints were not well filled, but not a greater number of such places than one would expect to find even in fairly good work. On the exterior the building was finished with stucco, which was tinted to imitate the grayish-green sandstone so much used for building purposes in San Francisco.

The city hall was of an irregular plan, as it was built on a triangular lot. The building contained in the western part an interior court, in which a nonfireproof structure had been erected prior to the earthquake and fire to accommodate the fire-alarm headquarters. On the southeast front of the building a little to the east of the center was a rotunda with a tower and dome above it. This tower was built of brickwork up to the base of the upper of two peristyles of free pillars around the outside of the tower. This peristyle was composed of steel columns covered with hollow tiles, so as to form a pillar of circular section with an entasis. The walls of the tower from the base of this peristyle up also seem to have been of hollow tiles. At the base of the dome was a floor composed of terra-cotta flat arches. It was reported that the masonry of the building had been reenforced to a great extent with embedded steel bars for the purpose of increasing its resistance to earthquake. I did not notice any such bars myself, but it was very difficult to get such access to the débris as would have permitted the verification of this point.

In a general way it may be said that the southwest half of the building was practically destroyed by the earthquake. The heavy masonry was thrown down, so that the entire southwest half of the tower was left entirely exposed, the dome standing on the steel work alone. The remaining half of the building showed considerable damage from the earthquake, but the principal damage here was due to the fire. Pl. XXXI gives a fair idea of the earthquake damage in the southwest half of the building.

It will be observed that some of the projecting pilasters on the exterior of the wall were badly cracked. A singular action of the earthquake, as exhibited here and in other places, was the tendency to shear off projecting pilasters even though they were built of the same material as the wall and well bonded to it. In my judgment this action was due to the fact that the earthquake caused the wall to rock slightly sidewise. When it rocked toward the side from which the pilasters projected, the entire weight would be for an instant concentrated on the base of the pilaster in such a way as to tend to shear it loose from the wall, which actually happened in many cases, the wall presenting no other evidence of damage whatsoever. Instances of this damage are pointed out in the discussion of other buildings.

Examination of Pl. XXXI, especially with a reading glass, will show that the diagonal braces in the steel work of the tower

were stretched beyond their elastic limit. I found, on personal examination in the field, that many of the wind struts had almost slipped from their seats on the columns. The bolt holes or rivet holes intended for bolts or rivets to hold the struts in place between their seats were not filled. Whether this was due to the fact that they had been sheared by the earthquake or whether they had been omitted in erection, I could not determine definitely. The latter will seem a plausible supposition to anyone familiar with the way in which the average erecting gang does its work. A few of the wind struts had absolutely slipped from their seats and fallen down; but it was not possible to determine from the visible evidence whether this damage was due to the earthquake or to the precipitation of the mass of masonry upon the struts as a result of the failure of the outer walls. Examination of the diagonal tie-rods made it apparent that some of them may have been stretched and bent by the mass of masonry falling upon them, but that others had very clearly been stretched beyond the elastic limit by the vibration of the tower during the earthquake. In inspecting the inside of the rotunda I observed considerable earthquake damage to the tower, including the stretching of a pair of diagonal tie-rods in the dome by the impact of the falling material. The terra-cotta floor at the base of the dome was absolutely intact, so far as could be determined. I made an effort to get out upon the steel work of the tower to climb it, but could only get as high as the gallery in the rotunda on a level with the upper floor of the main building. The means of access to the higher points had been evidently destroyed by the earthquake. The portion



a temporary platform covered with bunting, which had evidently been used on the occasion of some meeting, was practically undamaged, except for the material which had been precipitated upon it.

The main structure of the building itself, to the southwest of the tower, as shown in the foreground and to the left in Pl. XXXI, was badly racked by the earthquake. There was very little damage from fire in this part of the building. Either the vibration due to the earthquake or the impact of falling material removed a good deal of plaster from the walls in the part of the building immediately behind the two columns that are still standing, with the portion of the entablature that they supported. A large part of the building was entirely gutted by the fire, so that, in my judgment, it would cost about as much to remove the débris and restore this building as it cost to put up the building originally.

In the northwest corner of the building there was a pavilion which had a row of free columns still standing. In the middle of the west front of the building there had been a pavilion with a similar row of columns, all of which, with their entablatures, were precipitated into the street. These columns were composed of drums of cast iron with annular rebates which enabled them to be securely seated and centered on each other. The interior of each shaft was filled with broken-brick concrete of a very good quality. The columns were very heavy and massive, and it must have required an extremely severe shock to detach their entablatures from the rest of the building and then to throw the whole mass into the street.

The effect of the fire on the interior of the city hall was very interesting. Some parts of the ceiling remained in place sufficiently long to protect the corrugated-iron arches from damage; in fact, some of the ceiling did not come down at all. Such a case is presented in Pl. XXVI, *B*, which shows the incipient failure of a naked cast-iron column and a ceiling that was evidently on the point of coming down. Where the fire was intense it brought the ceiling down in time to permit serious damage to the corrugated-iron arches and their concrete filling. Wherever these arches were exposed directly to much heat the first effect was to cause them to expand and rise at the crown, which generally resulted in shattering the concrete filling immediately over the crown. Further application of the heat caused the corrugated-iron arch to soften and come down altogether. When it did, the concrete followed it, the portion at the crown being too much shattered to act as a key. In this way the total collapse of large areas of floor construction in the city hall was brought about. The concrete arch would have stood better alone than it did with corrugated iron underneath it; indeed, it is doubtful whether any of the concrete arches would have collapsed but for the damage done by the
the corrugated iron. The concrete was of a very fa

quality and the arches were very heavy. Many of the floor beams were 24 inches deep, and that was consequently the depth of concrete at the haunches. The thickness at the crown seems to have been not less than 5 or 6 inches, and the span between floor beams was not more than 6 or 7 feet. A concrete arch of such dimensions and such span, even though it had been made of very poor concrete, should have stood perfectly well had it been depending on its own power of resistance alone. In a number of places where the floor did not collapse the effect of heat on the exposed lower flanges of the 24-inch beams was sufficient to produce a deflection of 6 or 7 inches on a span of 25 or 30 feet. This result indicates clearly the necessity of protecting the exposed flanges of all beams.

Pl. XXVI, *B*, shows some unconsumed papers about the base of the cast-iron column. These papers came from a vault which opened into this room and the contents of which were charred, but not destroyed; all the combustible contents of the room proper were destroyed. The dark splotches on the wall in the background are due to spalling of the brickwork at the surface under the influence of the fire. This phenomenon was noticed in a number of places in San Francisco, just as it was in Baltimore; but as a rule the spalling did not penetrate to a greater depth than half an inch, and the wall itself was practically as good as before. In the fire at San Francisco, as in every other large fire, the right kind of brickwork proved to be more resistant than any other material.

A good deal of the plaster on the interior walls in the city hall was on wooden furring studs and wooden laths. Why this kind of



templates that were subjected to the heat were badly spalled and shattered, and one or two of them had failed sufficiently to permit the ends of the girders to settle an inch or more. I also noticed a number of places in the walls of the building where the fire had evidently found its way into the interior of unfilled joints through very small and tortuous passages.

The hall of records was connected with the city hall by means of an arcaded corridor. The building was circular and all the floors above the first were pierced so that they practically formed galleries. The beams supporting these upper floors or galleries were of steel, set radially and supported at their inner ends by girders carried on a peristyle of 12 circular cast-iron columns, which had no fireproof covering of any sort. The floor arches were segmental arches of common bricks. The lower flanges of the beams were exposed, but the evidence indicated that there must have been a suspended ceiling of some sort below the fireproof floor construction, although it was impossible to determine its nature. It is probable that it was carried on combustible supports of some kind, which have totally disappeared. As the records had been carried away from this building before the fire reached it the heat within it was not very intense and the interior of the structure was standing in a comparatively undamaged condition, except for finish. The exterior walls, however, were badly shattered by the earthquake. The window shutters were of iron, and if they had remained in place, considering the situation of this building, would probably have kept the fire out. As indicated in the view, however, the earthquake wrenched some of these shutters, with their surrounding masonry, entirely out of the wall, thereby, of course, leaving easy access for the flames.

As previously stated, it is my opinion that to remove the débris and restore the city hall, including the hall of records, to its original condition would cost as much as the entire building cost in the beginning. As it was so badly damaged by the shock it would apparently be wise to remove it altogether and build a structure of another type designed to resist earthquakes.

COWELL BUILDING.

No special interest attaches to the Cowell Building, except that it seems to have been more flimsy than the average. It had unprotected steel work and girders and wooden-joisted floors. The effect of fire on the unprotected steel work is well illustrated in Pl. LI, B.

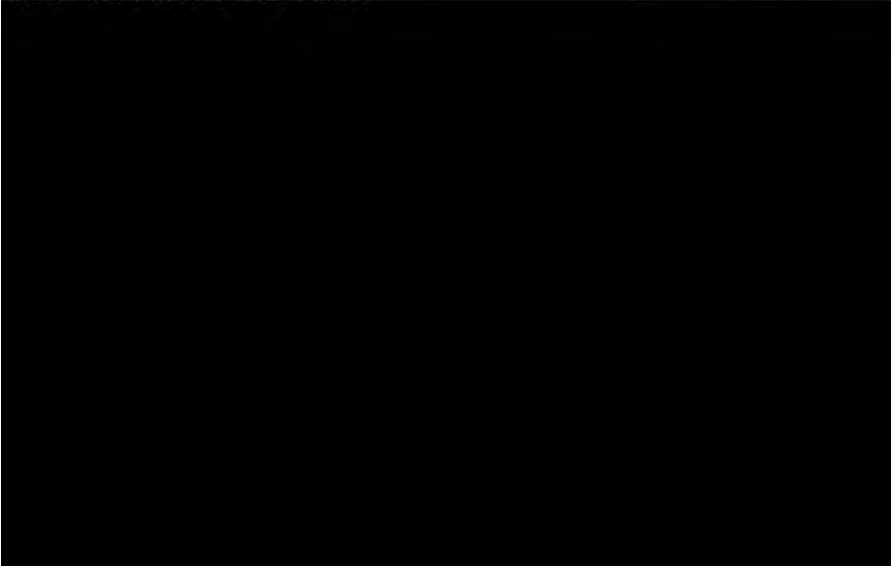
CROCKER BUILDING.

**The Crocker Building had a steel frame and hollow-tile fireproof-
ing of the tile arches had totally collapsed, and over 1**

areas—probably at least 30 per cent of the whole—they had lost their lower webs. There was nothing of special interest in this building more than has been described with other buildings. The damage seemed to be about as great as the average—probably more than 60 per cent.

CROCKER ESTATE BUILDING.

Pl. XXVIII, *B*, shows the kind of damage to ornamental terra cotta which is typical of both earthquake and fire action. This particular view was selected because it was possible to take it from a point near by so as to show the damage in detail. The Crocker Estate Building, a part of which is shown in the view, had cinder-concrete floor slabs, rolled beams and girders, and naked cast-iron columns. The fire was evidently not very hot in this building. The lower flanges of the beams and girders were covered with expanded metal and plaster. The webs of the beams were protected with cinder concrete built out solid from the webs to the edge of the flange. The rear portion of this building and a building of similar construction on the east had largely collapsed, apparently as a result of the action of the fire on the naked cast-iron columns. At this and every other point where exposed cast-iron columns had failed it was often noticed that the heads of the columns broke off and remained attached to girders and beams by means of the lugs and bolts. This result confirms conclusions derived from certain experiments made a number of years ago, to the effect that the lugs, ribs, etc., at the heads of cast-iron columns are the source of severe shrinkage stresses, with consequent weakness in the column.



reported that this building was dynamited three times during the progress of the fire, although I was assured by a policeman, who claimed to have been on duty during the whole time, that this report was not true. Under the circumstances, it is a little difficult to draw a reliable conclusion from the state of affairs in the Emporium. However, examination of the ruins indicated very strongly that much of the trouble was due to the inadequacy of the fireproof protection to the steel work.

Pl. XXXII, A, is a general view of the collapsed portion of the building and illustrates the failure of the terra-cotta column covering in various stages. The hollow-tile end-construction arches in the mezzanine floor had collapsed over considerable areas, under the influence of heat alone, as the evidence plainly indicated that nothing could have been precipitated upon them and that they were not subjected to an explosion. A considerable portion of the rear wall of the Emporium, which had been thrown down, probably partly by earthquake and partly by the fire, presented one case of very excellent mortar used in a commercial building. The mortar was better than the bricks, and both were of good quality. The fireproofing in the lower part of the building was quite as good as that ordinarily found in similar structures throughout the country. In fact, it would be easy to point out department stores not so well fireproofed as the lower part of the Emporium.

I have always been of the opinion that the Horne store in Pittsburgh, which was the first large fireproof department store to be tested by fire, was really closer to collapse from the heat than is generally believed. After the covering has been stripped from a steel column, the time and heat required to bring it down are not very great. The fact that the covering comes off during a fire is absolute proof that it is wholly inadequate. If the steel column stands up, notwithstanding the loss of its covering, it is due to good luck and not at all to good fireproofing. In the Horne store the covering was stripped from a number of columns; in the Emporium Building the same thing happened, but the heat continued a little longer, and there is no doubt in my mind, after an examination of the ruins, that at least a portion of the collapse was due to the failure of the columns under heat. The floor tiles in the Emporium Building lost their lower webs in large quantities, where the arches themselves did not collapse; and tiles in the column covering which did not come off bodily also lost their exposed webs in considerable quantities. The ruins of the Emporium were in a very dangerous condition, so that a detailed inspection was not practicable; and it is doubtful whether any useful results would have followed, because the fireproofing was of the ordinary commercial type which has not been enough proved inadequate to resist a serious fire.

FAIRMOUNT HOTEL.

The lower two stories of the Fairmount Hotel (Pl. XXXIV) were of concrete. The next story, the first, was built of granite, apparently backed with brickwork, and above that the building was faced with ornamental terra cotta. The earthquake damage to this terra cotta was severe. Neither the granite nor the concrete walls of this building seemed to have suffered materially from the earthquake, but the granite was badly damaged by the fire. The building was surrounded by a wide open space, and the fire must have been very fierce in its vicinity to have ignited it. I was informed that considerable damage was done to the steel work and fireproofing in this building; but as the owners, or at least those in charge, objected to having it inspected, and as it was an unfinished building, I made no examination of its interior. If, under the circumstances, it suffered seriously from the fire, the only conclusion that could have been drawn was that the fireproofing was very poorly done.

JAMES FLOOD BUILDING.

The new James Flood office building, situated on the north side of Market street, opposite the Emporium Building, had a steel frame, segmental hollow-tile floor arches, terra-cotta column covering and partitions, and furred ceilings of metal lath and plaster. The hollow-tile column covering and partitions failed in this building in the same manner as in others, and to about the same extent as in the average building. The lower stories seem to have been occupied for



and at each principal entrance there was a groined-arch ceiling made of it. These ceilings were so badly cracked and damaged that they will probably have to be taken down and rebuilt.

GRANT BUILDING.

The structure at Seventh and Market streets known as the Grant Building illustrated the capricious variation in intensity of the earthquake shock within short distances. This building was separated from the post-office by a very narrow street, hardly wider than an alley. The building had cinder-concrete floor slabs, furred ceilings in the upper stories, and terra-cotta partitions. Although it was a commercial building of very ordinary type, it was only slightly damaged by the earthquake, but was gutted by fire. It was entirely outside the area of surface disturbance, the streets in its vicinity showing no signs of settlement or upheaval. The fire was not very hot apparently, but was just about able to take the plaster off the under part of the floor construction without seriously damaging the latter. The terra-cotta partitions were all down. There was no evidence of superiority of construction, however, as everything pointed to moderate tests by both earthquake and fire.

HALL OF JUSTICE.

The Hall of Justice was one of the municipal buildings which was seriously damaged by the earthquake. A general view is shown in Pl. XXXIX, A, but does not bring out the damage that really occurred. In the basement of this building was another example of buckled columns. The columns were covered with expanded metal and plaster. This covering failed at a point near the floor, and the columns buckled and sank, producing the same effect as if they had been punched into the ground. The column coverings throughout this building failed very generally from the fire.

KAMM BUILDING.

The Kamm Building was situated on Market street, west of the Call Building. The rear portion was extended eastward by a short ell, so that it was wider than the front. It was occupied in the first story and basement by a wall-paper establishment. The columns were protected by metal lathing and plaster.

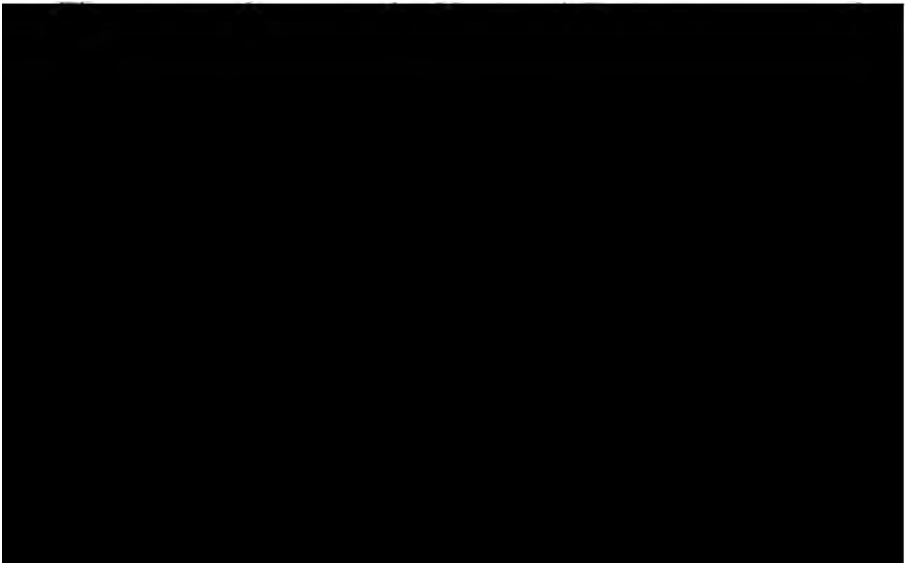
The burning of the wall paper in the basement caused general buckling of the basement columns to such an extent as to result in the collapse of all the interior framework of practically the entire rear portion of the building. A good view of this building is to be found in the *Engineering Record* of May 26, 1906, on page 645.

KOHL BUILDING.

The Kohl Building was of steel-frame construction faced with the grayish-green sandstone which is referred to so often. It had reenforced-concrete floors with furred ceilings and partitions of metal lath and plaster. The window frames and sash were metal covered, and there was very little combustible matter in the finish. The doors, with their frames and jambs, were of wood covered with sheet metal. It is manifest that this building was not subjected to very intense heat, as the windows above the fourth story were unbroken and the stone was comparatively undamaged. The first, second, and third stories were burned out, and there was some damage in both the fourth story and the attic.

The metal-covered doors in this building, however, prevented to some extent the spread of the fire within the building itself, so that where one room burned out, the fire coming in through a front window, an adjacent room was not burned because of the resistance offered by the door. The building could hardly have been subjected to a very fierce heat, however, for, if it had been, the light partitions would have failed, in which case the metal-covered doors would have been of no avail. Where the heat was really intense, the wood of doors, frames, and windows burned out under the metal anyway, but of course the metal covering delayed the ignition of the wood and later prevented it from burning freely.

MERCHANTS' EXCHANGE BUILDING.



without, however, producing any very large cracks. It is doubtful whether the wall is really safe in its present condition. On the inside of this building some of the wall columns were covered with 4 inches of brickwork projecting from the inner face of the wall as a pilaster. Some of these brick coverings had cracked almost entirely away from the main walls, besides being cracked vertically at other points in a manner similar to the cinder-concrete column coverings in the basement of the Aronson Building described on page 79. The brickwork in these places seemed to have been rather below the average in quality. It is not entirely certain whether the fire or the earthquake caused the cracks, but all the columns seem to have been uninjured, although the brickwork of one or two was so badly damaged that it ought to be taken down and rebuilt. Some enameled bricks were practically ruined by the fire, which stripped off the enamel face (Pl. XL, A).

MILLS BUILDING.

The large steel-frame Mills Building was without special bracing. The floors were of hollow tiles on the end-construction system, and the remainder of the fireproofing was likewise of hollow tiles. The tile arches lost their lower webs to a great extent, and some of them collapsed, apparently from heat alone; the column coverings failed very generally, and the girder coverings to a somewhat less extent (Pl. XLV, B). One basement column buckled under the action of the heat (Pl. XL, B). The conditions in the Mills Building as to column coverings and partitions were similar to those in the Aronson Building.

UNITED STATES MINT.

The mint was an old-fashioned monumental structure with granite walls and segmental brick-arch floor construction, carried on iron beams. A general view, showing the southwest front, is presented in Pl. XXXVIII, A. The building seems to have been practically uninjured by the earthquake, the only damage visible being at the base of the right-hand brick stack. It is probable that the shock at the locality of the mint was not so severe as it was at the new post-office building, although the two are only a few blocks apart; yet the result may be an indication that the solid old-fashioned monumental walls with the stonework solidly backed up by brickwork constitute after all one of the best types for resisting earthquake shocks.

It is somewhat surprising that the brick stacks were not overthrown, but I am informed that the thickness of the masonry in these stacks was very great, which probably explains their stability. The ~~southwest~~ (Pl. XXXVIII, B) and northeast faces of the mint wer

considerably damaged by the fire, but the fire was kept out of the building proper by means of water from an artesian well equipped with fire pumps, located in the building.

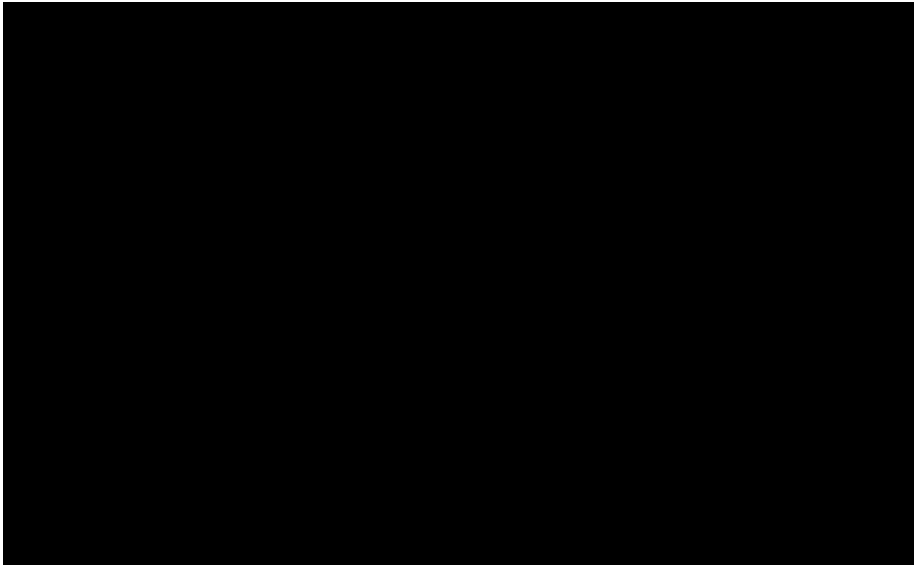
MONADNOCK BUILDING.

The structure known as the Monadnock Building was an ordinary steel-frame office building, which was in process of erection. It was badly racked by the earthquake. Every one of the piers in which the earthquake cracks appeared was so badly shattered that no repairs short of tearing down and rebuilding would suffice. As a matter of fact, it is probable that adequate repairs to the masonry in the front wall of this building would involve reconstructing more than half of it. It would appear that there must have been rather severe vibration to shatter the brickwork so badly. Whether the steel escaped injury is a question of considerable interest, which can not be settled until the masonry covering is taken off.

MUTUAL LIFE BUILDING.

The Mutual Life Building was a steel-frame structure of the same general type as the Mills Building, and it suffered in the same general way, though possibly not quite so much. Some of the floor arches had collapsed, apparently from falling weights of some sort. (See Pl. XLII, A.)

PACIFIC STATES TELEPHONE AND TELEGRAPH BUILDING.



history of the fire in this building I am indebted to S. A. Reed, consulting engineer for the committee of twenty of the National Board of Fire Underwriters. Mr. Reed states, however, that the history of the fire here must be largely surmise, because reliable evidence was not obtainable.

This company had also a building with reinforced-concrete floor construction and wire-glass protection for its windows for one of its branch exchanges. The exposure of this building was probably not very severe. It was three stories high and the fire got into the upper story and cleaned it out; but the floor construction prevented the fire from extending into the stories below, which suffered practically no damage to structure or contents. A part of the third-story wall was thrown down either by the earthquake or by some other means, and this damage may have opened a way for the entrance of the fire.

PALACE HOTEL.

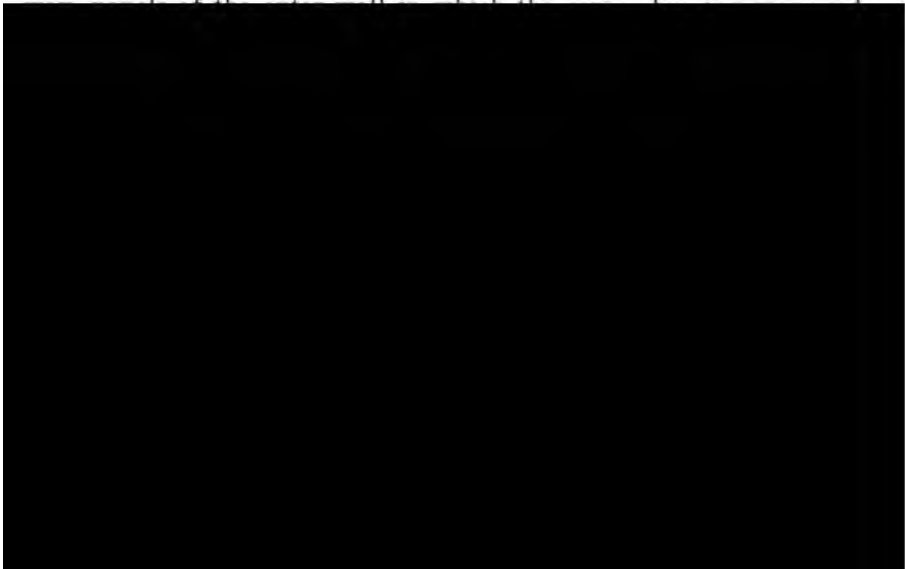
All of the interior and the exterior walls of the Palace Hotel, on the south side of Market street, were built of brickwork. It is reported that the brickwork was reinforced with embedded iron bars. The structure stood remarkably well, and there is little indication of earthquake damage. The building was nonfireproof, and was, of course, completely burned out, but the walls still stand almost as good as ever. (See Pl. XXX, *B*.)

POST-OFFICE BUILDING.

The steel-frame and granite post-office building (Pls. XLII, *B*; XLIII; XLIV) was carried on isolated grillage foundations, each column having its own footing. The diagonals of the building ran nearly north and south and east and west, the south corner being at Seventh and Mission streets. To the south and west of Mission street was an elongated, narrow, curved area in which the earthquake damage was very severe. It was commonly reported that this area, which was not far from the south corner of the post-office building, was a stream bed or ravine that had been filled within the recollection of the older inhabitants of San Francisco. Through the courtesy of J. W. Roberts, the local representative of the Supervising Architect's Office of the Treasury Department, I was enabled to make a detailed inspection of the building, and he also gave me very complete information as to the history of the building and the causes of the various items of damage which were in evidence at the time of my inspection. Mr. Roberts, who is evidently a cool and accurate observer, seemed of the opinion that the material under the building was a natural deposit, and not an artificial fill. But toward

the south it was not of a nature to inspire confidence in its carrying power at the depth shown on the foundation plans. He accordingly obtained authority to lower the footings wherever the material at the depth shown on the plans seemed unreliable, so that the footings of the south half of the building were lowered—some of them, as I remember his statements, to a depth of 20 feet or more below the basement-floor level. At any rate, he carried them to a point where the material, in his judgment, was sufficiently hard and compact. All this underlying material is very sandy; but at considerable depths, I understand, gravel appears, and the combination is almost as hard as hardpan.

The walls, floors, and all parts of the post-office building proper are carried on the steel frame. The outer walls consist of a granite facing, carried on the steel work at each floor level. The granite is not backed up in the usual way, the backing having been omitted to save weight. Some distance behind the granite an inner wall was built of hollow terra-cotta blocks. The space between the granite and the terra cotta was used for the passage of pipes, air flues, etc. The granite was heavily anchored to the steel work. In a number of panels of the steel work corner braces made of a pair of channels were used, and they were fastened as far down on the columns and as near to the center of the wall girder that spanned the space between the columns as the window openings would permit. There was also some portal bracing in a part of the building over which it had been intended to erect a tower. This intention was afterwards abandoned, but I understand the bracing was in place. In a general



more important rooms had a great deal of expensive and beautiful marble finish; there was much marble-mosaic ceiling work, and the finished woodwork was of extraordinary richness. On top of the buildings were a number of chimneys built of granite blocks with terra-cotta linings.

All the materials entering into the construction and finish of this building were the best of their kind, and the workmanship, under the efficient supervision of Mr. Roberts, was as nearly perfect as it is possible to make it. I have never seen work better done, and have rarely seen it so well done. To one who knows and appreciates good work it is a continual pleasure to see everywhere in the San Francisco post-office the record of sleepless vigilance and skilled labor. Where the structural parts were laid bare by the damage due to the earthquake, the same story was told by the minutest details as well as the roughest parts of the work—everything was the best of its kind. It is therefore of great interest to study the effect of the earthquake on this structure, for the care with which it was built must have made it fully as good as its designers could have hoped. Moreover, I am inclined to think that it received a more severe shaking than any other building in the congested district of San Francisco that was at all comparable with it. The city hall was badly racked, but, to judge from the condition of the adjacent street surfaces and the surrounding ruins, the shock was much less severe than that to which the post-office was subjected. For instance, there was a partially erected steel frame (Pl. XLII, *B*) on the southwest side of Seventh street, near the post-office. Before the earthquake all the columns were plumb and in true alignment. As a result of the shock there was a lateral shifting of the column bases—the relative movement being almost 2 feet in some places—at the cellar-floor level. The basement walls of the incomplete building were also shifted horizontally; at the east corner, where the walls had met at a right angle, they had been ruptured by a vertical crack and moved laterally in such a way that the angle between them was reduced to about 75° , as nearly as I could estimate it without taking measurements.

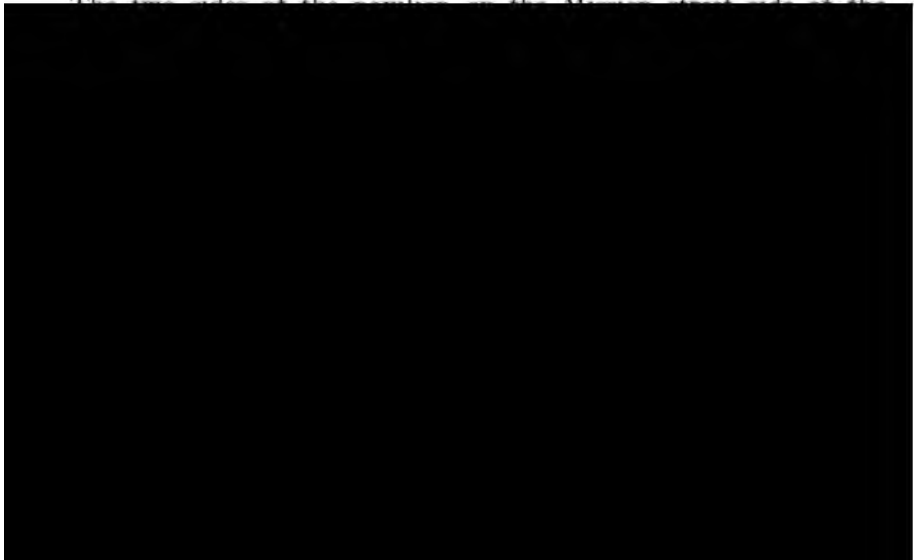
The south corner of the post-office building is shown in Pl. XLIV, *A*. Mr. Roberts states that accurate measurements show that the building proper settled a little at this point, but not more than one-eighth inch relative to other parts of the structure. The general appearance of the building bears out this statement. The result is remarkably gratifying when the great extent of the near-by surface disturbance on Mission street is considered. The street went down about 4 or 5 feet at this point as a result of the earthquake (Pl. XLIII, *B*). The molded granite shelf surrounding the building, shown with small timber props under it in Pl. XLIV, *A*, was set into the main wall of the building. When the sidewalk a

the supporting granite curb settled away from the shelf, it remained in position, as a cantilever, but the props were put under it to keep it from being broken. In the basement no evidence of the earthquake could be found, except a few insignificant cracks in the concrete floor, which Mr. Roberts says were not there before the earthquake.

On the whole, I think it is fair to say that the post-office was subjected to an extraordinarily severe test. About half of the chimneys were thrown down. One of them either rocked on its base or was thrown upward far enough to cause the counterflashing, which lapped the flashing about 3 inches, to clear the flashing and come down inside of it. The chimney remained upright, but with a slight horizontal displacement. In the exterior walls a good many stones were started from their beds, and some were cracked. Two or three fell from the wall. At least one anchor was exposed, and it had been broken. Whether the steel work was damaged or not could not be determined, as it was not sufficiently exposed. The damage to the exterior walls is fairly well shown in Pls. XLIII, A, and XLIV.

Pl. XLIII, A, shows damage on the southwest side of the west corner of the building; the surface of the window reveal and the adjacent return of the upper molding on the sill, at the point indicated by the arrow, were separated at least three-fourths of an inch, yet during the earthquake they were jostled together with sufficient force to abrade the reveal and spall the sill. That this effect should have taken place without shattering all the masonry around the window opening is one of the many inexplicable phenomena that seem characteristic of earthquakes.

The two sides of the sill in the Mission street side of the



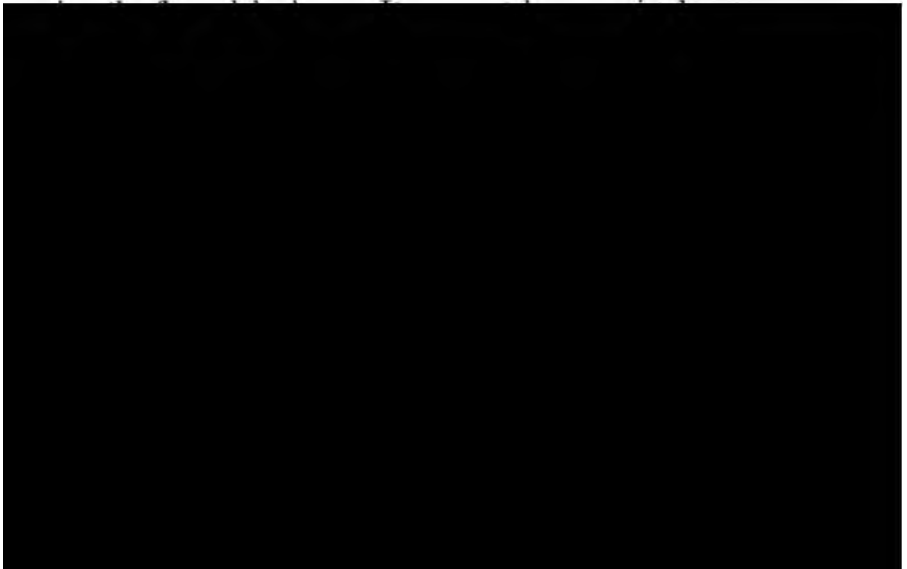
A great many marble slabs were thrown down by the concussion due to the dynamiting of dangerous walls at Seventh and Market streets, less than half a block away. The damage to marble finish from this cause was much greater than that due to the earthquake. Although the slabs brought down by the dynamite may have been loosened by the earthquake, they could have been taken down and reset if the dynamite had not caused their total loss. In one sense much of the loss was irreparable, for adjacent slabs were beautifully matched by being sawed from the same block and then so set in groups of two or four that the veining was symmetrical about the joints. Where one slab of a group was destroyed the only way to restore the finish to its original beauty would be to renew the whole group. In addition to injuring the marble finish, the dynamite did much damage by blowing windows, transoms, and doors from their frames, and by blowing panels out of doors and glass out of windows. With the kind of woodwork used in this building and with plate glass in all the windows, this item of damage was very heavy. Débris from the demolished buildings, also, was thrown across the street and came down through one or two skylights in the post-office building. It was only owing to good luck that some of the employees were not killed or seriously injured. As it was, the interiors of one or two expensively finished rooms were almost wrecked. All the items of damage which Mr. Roberts ascribed to the dynamite were of the same general type as those due to the concussion in mortar batteries, etc. The chief engineer of the building stated that he and some of his subordinates, although down in the basement, were thrown to the floor by the force of one of the dynamite explosions, and that the electric lights were extinguished for several seconds, although the engines kept running. Probably the concussion lifted the brushes from the commutators of the generators. It seems probable, from what evidence I was able to gather, that at first the dynamite was used in rather large quantities without tamping; but later it was used in a more tentative way and tamped with sand bags. By this policy those in charge of the later blasting operations finally got the work down to a system whereby a wall was brought down within a distance of 20 feet from the base on either side without any dangerous hurling of débris beyond that distance. So far as I was able to learn, after the work had reached this stage no one noticed any damage to neighboring structures, and, in fact, very few people were aware that blasting was in progress.

Some of the mosaic ceilings in the post-office building were planted on a terra-cotta base, others on a furring of metal lathing and plaster. The former were seriously damaged by the earthquake, but the latter remained intact. As previously stated, the interior walls

in the post-office were built of 6-inch terra-cotta blocks, with webs nearly 1 inch thick. They were beautifully built, every joint being absolutely filled with cement mortar that was much harder than the tiles, though the latter were of exceptionally good quality. None of these walls were thrown down, but many of them showed the intersecting diagonal cracks that are characteristic of earthquake action. The tiles along the lines of the cracks were so badly shattered that many of them will have to come out. As a contrast, reference is made to Pl. XLVI, *B*, showing earthquake damage to good brickwork. In the tile wall the same cracks appear, but the tiles are badly shattered for some distance on either side. In addition, in much of the flimsy tile work in the commercial buildings the adhesion of the mortar in the entire partition, if there was any, was destroyed. In the concrete walls at Palo Alto a few cracks appeared here and there as a result of the earthquake; but they were even sharper and narrower than the crack shown in Pl. XLVI, *B*, and there was no shattering effect whatever.

The column coverings in the mail-handling room, described above, were absolutely uninjured, but the circular brick walls around the spiral stairways developed many rather ugly spiral cracks. Such cracks were very conspicuous also in circular smokestacks, where the damaged work was not thrown down entirely.

The floor construction in the post-office was absolutely undamaged by the earthquake. This was one building where "cinder concrete" was made as it should be—of well-burned clinker only. In the court room which burned out a part of the furred ceiling came down, ex-



cisco combined. It is my personal opinion that the results would have indicated to private owners the availability of a desirable form of fire insurance at moderate cost on which but one premium would have to be paid.

The post-office building was so carefully and intelligently designed and so well executed, and, all things considered, gave so good an account of itself, that it seems a little presumptuous to suggest wherein it could be made better. Yet I believe that if the granite had been solidly backed with good brickwork and even more heavily anchored to the steel frame, if the frame had been more completely and heavily braced, and if all the interior partitions had been of solid brickwork, the structural damage would have been much less; and even the greater weight on the foundations might have been an advantage rather than otherwise. Mr. Roberts estimates the total damage as about \$400,000. Of this damage more than one-fourth, much of which was caused by the dynamite, is charged to marble finish and plate glass. The cost of the building was about \$2,500,000.

RIALTO BUILDING.

The Rialto Building was a steel-frame structure, with expanded-metal and cinder-concrete slabs, expanded-metal and plaster column covering, and furred expanded-metal ceiling. It had two main wings, in each of which it is said attempts were made to dynamite the building, the explosions causing the collapse of a portion of the interior structural work. A hole in the roof was produced by the same cause. Pl. XLVIII, *B*, a view of the southeast corner of the building, shows a portion of this damage at close range, and is submitted to show the effect of dynamite on a steel-frame building.

The fact that the building was dynamited makes it impossible to draw any useful conclusions as to its fire-resisting qualities; but there seems to have been only a moderately hot fire in this building, and the fireproofing, while seriously damaged, was not a total failure as a result of the fire alone. The north front was badly racked by the earthquake, resulting in many cracks in the walls. The south front of this building was also damaged by the earthquake; the intersecting diagonal cracks in the walls were plainly visible. A considerable amount of face brickwork was thrown off on this front, probably owing to the fact that it was laid without bond.

ST. FRANCIS HOTEL.

The new St. Francis Hotel, which had been occupied but a short time, had a sandstone front and was supported by columns protected with cinder concrete. These columns were entirely undamaged a section near the upper end of each column v

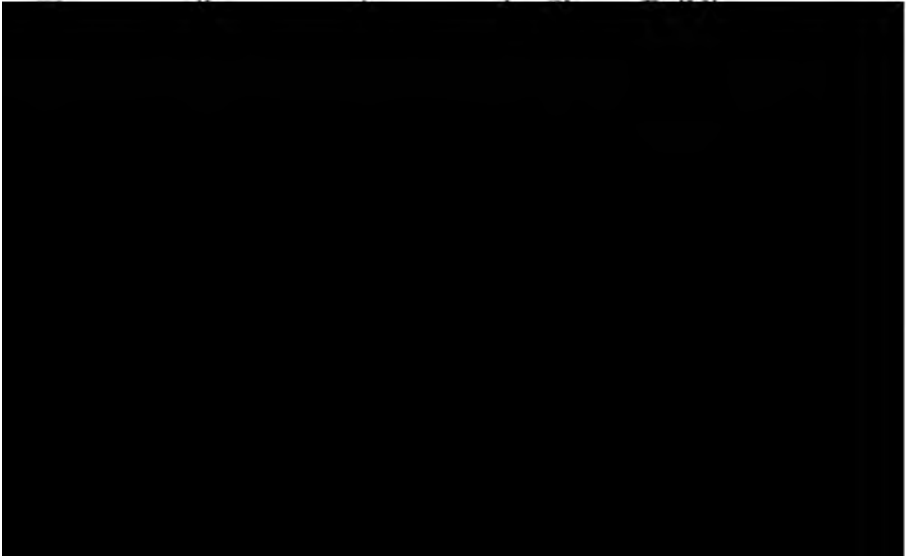
had apparently been covered in by a furred beam, or other architectural feature, since destroyed, was entirely devoid of protective covering. A great many people in San Francisco regarded the behavior of these columns as a substantial recommendation of cinder concrete, but the whole building bears evidence of having been subjected to only a moderate heat.

SHREVE BUILDING.

The columns in the first and second stories of the Shreve Building were covered with cinder concrete; those in the upper stories with hollow tiles. All the evidence in this building points to a moderate heat. The plastering on the columns was not seriously damaged, and such plastering never stands an intense heat. The hollow tiles on the columns came off very generally, but it is probable that the heat was more intense in the upper portion of the building than in the lower portion. This theory is supported by the fact that the damage to the masonry adjacent to the windows was most severe in the upper stories.

This building, like the St. Francis Hotel, is cited as an example of the excellent behavior of cinder concrete as a column covering, but in this case also there is every reason to believe that the concrete did not receive a severe test. The only cinder-concrete covering I saw that had evidently received an extreme test was in the basement of the Aronson Building, as described on page 79.

SLOANE BUILDING.



basement or first-story columns under the action of the heat. Pl. XLV, A, is a view taken in the first story of this building, which had been occupied by the City of Paris Dry Goods Company. This view is submitted as illustrating a typical but rather bad example of the loss of lower webs from hollow-tile floor arches. The column coverings shown in the view had suffered about as little as any others. The coverings of other columns in the same building were practically destroyed, as were also the partitions. The same sort of damage as that shown in Pl. XLV, A, was plainly visible in some of the upper stories of this building, especially the second story.

A stairway carried on unprotected cast-iron strings was destroyed by the heat in this building. The same thing occurred in a number of other buildings in San Francisco, even where the stairways had been walled off by hollow-tile partitions or by partitions made of light studs, metal lathing, and plaster. It has generally been considered—in commercial work, at any rate—unnecessary to protect a stairway carried on cast-iron strings, but the San Francisco fire showed that some form of protection is very essential. Where the inclosing partitions did not fail, the stairways were of course not seriously damaged, but as a matter of fact the partitions failed almost everywhere in San Francisco.

UNION FERRY BUILDING.

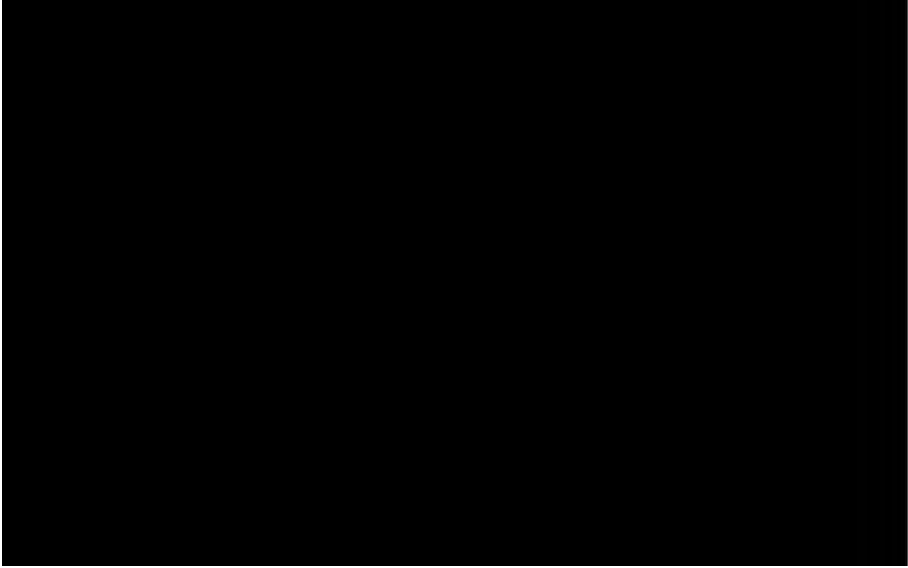
The Union Ferry Building (Pl. XLVI, A) is a large structure—practically of monumental proportions—which forms the terminus of all the ferry lines plying between San Francisco and various other points on the bay. It is built on piles, with heavy stone walls, backed with brickwork. The stone is the grayish-green sandstone elsewhere described. The floor construction consists of steel beams and girders, with stone-concrete slabs reenforced with expanded metal. The lower flanges or girders and beams were not protected. Near the center of the west front a high tower rises to a considerable distance above the building. The fire did not gain entrance, but the building was very seriously racked and damaged by the earthquake. The damage was not at all of a fatal nature, however, and the building was kept in practically continuous operation as a ferry terminus. The tower, which was built with a braced steel frame, inclosed to a height of several stories with a heavy wall composed of sandstone backed with brick, and closed in with wood and sheet metal above the masonry part, was so badly damaged that the masonry walls were being removed at the time of my inspection. To judge by the effects on this tower, the greatest intensity of the earthquake vibration must have been from northwest to southeast. The bracing was badly strain-

and in this case there can be no question that the effect was entirely due to the earthquake. The masonry in the tower was of an admirable quality.

In Pl. XLVI, *B*, is shown a crack in the brick masonry on the inside of the tower, together with a part of a diagonal tie-rod which had been stretched beyond the elastic limit and was hanging with a noticeable sag. It will be noted that the brickwork was well bonded and that the joints were well filled. The mortar was much harder than the bricks, but both were of good quality. It is also evident from this view that there was no general shattering of the entire mass; there was a well-defined crack, but nothing else.

At the northwest corner of the tower, about halfway from the roof of the main building to the top of the masonry walls of the tower, a diagonal tie-rod had been fastened to the wall girder by means of a gusset plate, with eight rivets in it. Seven of these rivets were sheared under the action of the earthquake, leaving the plate hanging by the eighth rivet at the time I saw it (Pl. XLVII, *B*).

One detail of the bracing in the ferry-building tower, of which a satisfactory photograph could not be procured, was as follows: The wall girders at the different floor levels were utilized for the wind struts of the bracing. In the lower part of the tower the diagonal tie-rods were fastened directly to the wind struts. The ends of the wind struts rested between upper and lower seats attached to the columns, and were, as a rule, bolted to each of those seats with nothing but two $\frac{7}{8}$ -inch bolts, the idea evidently being that, as the struts resisted compression only, it was not necessary to fasten



is ordinarily done. In fact, if the diagonal is to be fastened directly to the wind strut, there should be a connection between the strut and the column capable of taking up the horizontal component of the stress in the diagonals. Knee braces, such as those used in the Call Building, possess a manifest superiority over ordinary bracket seats in construction of this sort. An examination of the condition of the bracing in the ferry-building tower can leave no doubt whatever that the tower was just on the point of total collapse. Conditions were so bad that the superintendent of the contracting firm that was taking the masonry down evidently felt a little uneasy about what would happen when the masonry covering was removed from the portion of the steel work where the bracing was most seriously damaged. He was proceeding with great judgment and caution, however, and no doubt succeeded not only in removing the damaged masonry with safety, but in so tying together the steel work as to avoid all danger of collapse.

A part of the masonry in the east front of the tower was precipitated from its position (Pl. XLVI, 4) and fell through the skylight and onto the floor of the corridor in the upper story of the main building. This floor consisted of stone concrete, reenforced with expanded metal, and carried by steel beams with spans apparently of 7 or 8 feet. The contractor's superintendent, already mentioned, told me that he thought the amount of masonry so precipitated on this floor amounted to 30 or 40 tons. It punched in the floor one small hole not much larger than a man's fist, but nothing of any size got through. It is doubtful whether any form of floor arch or slab except reenforced concrete and possibly solid brick would have stood this test so successfully. Certainly no hollow-tile floor such as those in ordinary use would have stood it for a moment; the falling mass would have gone on through to the ground.

Along the west front of the ferry building, about halfway up the second-story window piers, most of the stonework had slipped about an inch. Some of the first-story piers were so badly shattered by the earthquake that they had to be boxed in to prevent the loose stone from falling. There were in the floor construction of the tower and of the building proper a few cracks which I thought might be due to the earthquake, although it is possible that they may have been shrinkage cracks. I was not able to get any convincing testimony on this point, but I have seen a good many shrinkage cracks and am of the opinion that most of these cracks were due to the earthquake and not to shrinkage. On the whole, the ferry building stood the shock remarkably well. It would seem to be the part of wisdom, however, to tear the tower down altogether and not to rebuild it.

UNION TRUST COMPANY'S BUILDING.

The ordinary steel-frame Union Trust Building, with terra-cotta fireproofing, came through the earthquake in about the same condition as the average fireproof building in Baltimore after the fire. From the exterior it presented the appearance of having stood the ordeal about as well as any other building in San Francisco that was completely gutted. The damage, however, was probably at least as great as that suffered by such buildings as the Continental Trust in Baltimore. Lower webs were off in many places, and column and girder coverings were damaged to a considerable extent (Pl. L, *B*).

MISCELLANEOUS STRUCTURES.

GENERAL DISCUSSION.

A number of buildings of fire-resistant construction in San Francisco, such as the Mutual Savings Bank, the Hibernia Bank (see Pl. XXXVII, *A*), and several others, have not been specifically mentioned in this report, but they presented nothing of more than ordinary interest. Detailed descriptions have been given of at least one example of everything that was typical, and practically everything described in detail was typical of many other cases of the same general class.

A building at First and Natoma streets had naked cast-iron columns, steel girders, reinforced-concrete beams from girder to girder, and reinforced-concrete slabs from beam to beam. The



It will be noted that there was no reenforced-concrete construction, pure and simple, in San Francisco. The warehouse of the Bekins Van and Storage Company (Pl. XXVII, *A*), in process of construction, had reenforced-concrete columns and floor construction and brick walls. The walls were badly damaged by the earthquake, but the reenforced concrete was absolutely uninjured. This building, however, was unfinished, and the lower portion of it was not subjected to the stresses which would have resulted had it been complete, with all its contents. In that case the energy due to the vibration of the greater superincumbent mass might have produced effects which were not produced in its unfinished condition.

One-half of the circular observatory on Strawberry Hill, in Golden Gate Park (Pl. XXIII, *A*), was thrown down by the earthquake. I did not make a personal examination of it, except from a distance, but was informed that it had been reenforced with heavy iron rods bedded in the masonry. It was reported to me that these rods were broken at the point where the collapsed portion had separated from the part still standing. The general effect of the earthquake on hollow circular structures of all sorts seems to have been a tendency to increase their diameter. Where this tendency was very marked, it naturally caused their collapse.

Practically all the other photographs submitted and not specifically referred to in the foregoing pages were taken with a view of showing earthquake damage. The tower of the church next to the old Mission Dolores was dangerously near being thrown down, and had to be pulled down later, as shown in Pl. XXIII, *B*. Pl. XXXVII, *B*, is a view of a brewery which had been four stories high, with a tower at the corner extending to a considerably greater height than the building. The damage was due to earthquake alone. Pl. XXI, *A*, shows a case of earthquake damage pure and simple. It will be observed that the face bricks were not bonded, and were thrown down in large quantities. None of the brickwork in this building seems to have been of a very good quality.

An old-fashioned brick building of ordinary construction near Fort Mason appeared to have survived the earthquake absolutely undamaged. This example indicates the variation in the intensity of the earthquake within relatively short distances.

Pl. XXXIII, *A*, shows a building, known as the Butler Building, which was partially completed at the time of the earthquake. When I first saw it the side wall, which appears in the illustration as nearly torn down, was standing at about the same height as the front wall (shown at the right side of the picture). This side wall had a few earthquake cracks in it which were plainly visible, but it was a matter of surprise to see, a few days later, that the wall had been torn down; for if this wall was damaged sufficiently

justify its destruction, a great many walls of other steel-frame buildings ought to have come down also. This building was of the ordinary steel-frame type, without any bracing. The walls were very light, and on the principal fronts they were pretty well shaken to pieces. A superficial examination indicated that they were much more seriously damaged than the side wall which had been torn down. This building appears in the background of the view of the Dewey monument (Pl. XXX, A). At the time this view was taken a considerable amount of the masonry in the front wall had been removed, but there was still a great deal which, in my judgment, was too badly damaged to be safely left.

Pl. LV is a panorama taken from Pine and Powell streets. The building on the left side of the street at the left is the Merchants' Exchange. To the right, just behind the high ground and trees, is the Mills Building, and farther to the right is the Union Trust Building. The other buildings will probably be recognized by persons who are more or less familiar with the city; the names of the chief ones are given on the plate. It will be observed that this panorama covers an arc of nearly 180°. The Twin Peaks appear some distance to the right of the city hall.

ORDINARY BUILDINGS AND RESIDENCES.

The effect of the earthquake on miscellaneous buildings of the cheaper class was more or less interesting. There were a number of brick dwellings in San Francisco faced with arch bricks laid in Flemish bond. These bricks, of course, are considerably harder and stronger than ordinary red bricks. Though they make a very rough



As a result of my observations, I am inclined to think that a building of the following type would be very desirable for residential purposes in an earthquake country:

The frame should be of timber, rather heavy and thoroughly braced, with all the vertical members continuous from bottom to top, or else thoroughly spliced. The horizontal members should be made as nearly continuous as possible—preferably by full splices. Horizontal and vertical members should also be fastened together as rigidly as possible, diagonal braces being used wherever conditions will permit. The frame should be covered on the outside with expanded metal and this metal plastered on both sides, a good deal of cement being used in the plaster. The exterior can be finished in stucco or pebble dash, as desired. The interior of the frame should be covered with expanded-metal lathing and the ordinary interior plaster-finish put on. The ceilings also should be finished with expanded metal and plaster. In my judgment, a building of this sort could be put up for very little more than the cost of an ordinary frame dwelling, and would not only come through an earthquake much better, but would be very much more difficult to set on fire and would burn much more slowly after it was on fire.

CHIMNEYS.

Chimneys seemed to be shaken down by the earthquake everywhere; even where there was no other damage this result was almost universal. The chimneys, as a rule, were built of bricks laid in lime mortar, and generally broke off at the point where they came through the roof. Reenforced-concrete chimneys with a terra-cotta lining would be very little more expensive than the kind that were ordinarily used in San Francisco, and would have suffered very much less damage. If any chimney projects a considerable distance above the roof, it would be advisable to brace it near its upper end to the roof in some way, so that it would not be free to vibrate. It seems probable that this plan might have saved some of the chimneys that failed. Appearances seemed also to warrant the conclusion that in the vibration some chimneys were brought up short against the roof framing and thus caused to break off at this point. If there had been a little more room for relative vibration between the chimney and the framing, it seems possible that some of these chimneys would not have fallen. The best way to prevent such damage is to build the chimneys of reenforced concrete or of some other material that has both rigidity and great tensile strength. Such chimneys would not ordinarily break off, even though they jostled against the roof timbers.

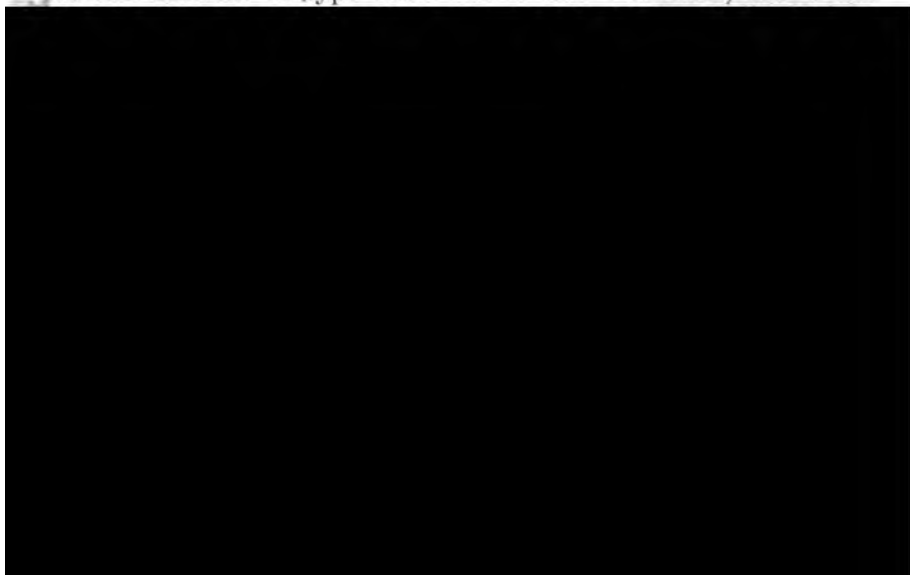
BRICK SMOKESTACKS.

There were a great many brick smokestacks in San Francisco, nearly all of which suffered more or less damage. For some reason circular stacks seemed to suffer more than square ones, but the number of square stacks in evidence was not sufficient to justify general conclusions.

The views of brick stacks speak for themselves to a great extent. The stack of the Valencia street power station (Pl. LIII, A) was of some interest because of its peculiar cross section—an eight-pointed star. At the vertices of two diametrically opposite reentrant angles the stack was split practically from top to bottom. The ruins of a circular stack, situated near San Jose, are shown in Pl. XIII, A.

CONDITIONS OUTSIDE OF SAN FRANCISCO.**OAKLAND.**

I made one trip to Oakland and went through the greater part of the town. A good many chimneys had been shaken down and the front walls of a number of ordinary brick buildings had been precipitated into the street. Several steel-frame buildings faced with sandstone were badly racked, and in places some of the stone had been shaken into the street. Some of the steel-frame buildings showed the same kind of damage as the Monadnock and new Chronicle buildings in San Francisco. The damage in Oakland in general was not different in type from that in San Francisco, but it was



Much of it consisted of rubble made of very small pieces of stone, apparently gathered up where stonecutters had been working. Many of these spalls were not larger than a man's fist, and in places 4 or 5 square feet of the wall was entirely backed up with this material. The bonding of the stone facing to the backing seemed to be less thorough in the new buildings than in the old. In short, the newer buildings conformed rather to the modern commercial standard of building construction; the old ones approached the monumental. The newer buildings suffered materially more than the old. They were not, however, of a type that would indicate culpable negligence or incapacity on the part of anyone connected with their design and erection, although they were distinctly inferior in type to the older buildings. The mortar used was not by any means poor. It seems to have been lime mortar gaged with cement. I tried it at a number of points where the buildings had suffered very severely, and it was distinctly better than the average mortar found in ordinary commercial work, although not as good as straight cement mortar would have been.

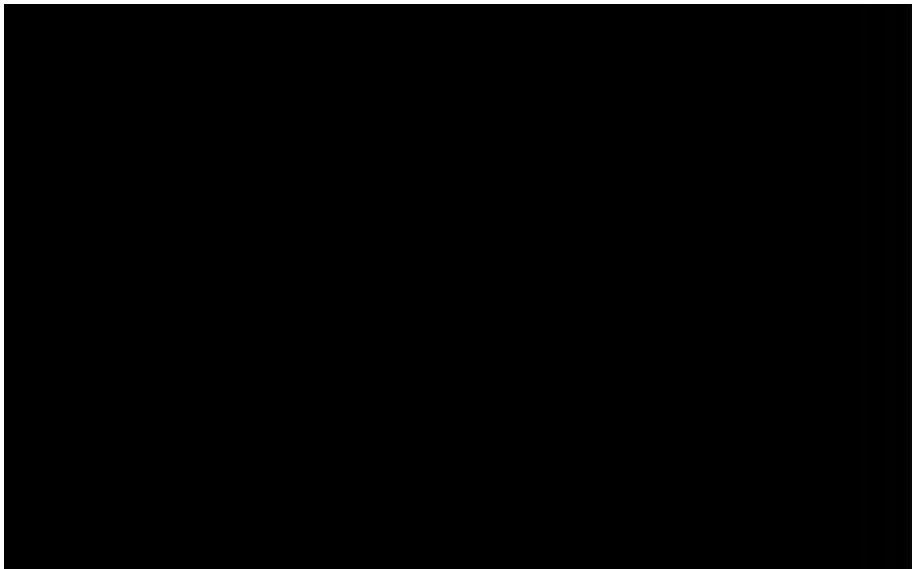
The buildings of the third class at Stanford University were built of concrete. The girls' dormitory had concrete walls and timber interior construction, and in the central portion of the Leland Stanford Junior Museum, the oldest part of the building, the walls and interior construction were of reenforced concrete. There were two wings, built of brickwork, with reenforced-concrete floor construction. It is reasonable to suppose that the intensity of the force applied to this building by the earthquake was nearly uniform over the entire structure. The two brick wings were practically shaken down, suffering, I should judge, considerably more than 50 per cent damage. The reenforced-concrete central portion, viewed from the exterior, seemed absolutely undamaged. In the interior a few cracks had opened up, but they were not of serious consequence. I should judge that a thousand dollars would easily cover all the repairs to this part of the building. Its valuable contents were, to a large extent, thrown to the floors and smashed, involving a considerable loss; but the structure itself suffered almost no injury. The only damage to the girls' dormitory was caused by a chimney that toppled over and crashed down through the roof, doing some damage on the inside. By good luck, no one was hurt in this building. The concrete wall showed one or two cracks, which, however, were said to be shrinkage cracks that had appeared soon after the building was finished. The earthquake apparently had caused no visible damage of any sort in the exterior walls.

It was noticed that those buildings which had completely trussed roofs suffered much less than those in which the walls had to take

the thrust of the rafters. This result was naturally to be expected, and indicates that in earthquake countries walls should not be subjected to the thrust of the rafters at all. The damage at the university also indicated clearly the necessity of thoroughly tying all the walls to the roof construction, gable walls as well as others. The university post-office building was said to be of reenforced concrete and undamaged. Very good illustrations of the damage at Stanford University can be seen in the *Engineering News* for May 10, 1906, and in the *Engineering Record* for May 12, 1906. (See also Pls. XIV, A; XV; XVI; XVII, B; XVIII.) A concrete-block building in the town of Palo Alto was totally demolished.

OTHER TOWNS.

Concrete-block buildings elsewhere were also reported as totally destroyed. The various structures of the Southern Pacific Railroad along the coast division had suffered more or less damage. One or two stations faced with a sandstone similar to that used at the Leland Stanford Junior University, and built in the ordinary style, had been very seriously damaged. One station, which seemed to have been built a little more carefully and with larger stones than the rest, was in very much better condition than most of them. The city hall at Redwood had a central circular tower, with a dome supported on steel work, much as in the city hall at San Francisco (Pl. XXXI), though on a smaller scale, and suffered almost exactly the same kind and degree of damage.



formerly the main dam, when the reservoir was smaller than it is now. The concrete dam, which was parallel to the fault and of course very near to it, was absolutely uninjured (Pl. XI, *B*); the earth dam, which lay across the fault approximately at right angles, showed definite signs of disturbance and lateral displacement. Longitudinal and transverse cracks appeared on top of the earth dam, and some of the former were reported to have extended to a depth of at least 3 or 4 feet. The transverse cracks were said to be less well defined and to indicate rather a general disturbance on each side of the fault line, about one-fourth of a mile away, and was absolutely to which it was damaged could not be ascertained.

San Andreas Lake is retained by a high earth dam. The fault ran under the east end of this dam and produced considerable disturbance over a strip about 150 feet wide, though the dam was not seriously injured. A concrete culvert inlet was connected with this dam, and one of the worst transverse cracks noted ran diagonally over the culvert, but the culvert itself was uninjured. Besides the high concrete dam of Crystal Springs Lake, the water company had another smaller concrete dam at Searsville. This dam also was parallel to the fault line, about one-fourth of a mile away, and was absolutely uninjured.

The Spring Valley Water Company had three main conduits running into San Francisco. One of these, known as the Pilarcitos conduit, consisted largely of 22-inch and 30-inch riveted pipe and 24-inch cast-iron pipe; some feeders were built of wooden flume. The conduit crossed and recrossed the line of the fault, and was so badly wrecked that the company has decided to abandon it—no doubt a wise decision, because the location along the line of the fault was a very bad one. Wherever the conduit crossed the fault line it was destroyed. In some places there was a longitudinal displacement of as much as 84 inches, which either telescoped the pipe or pulled it apart, as the case might be. (Views of these effects are given in Pl. IX.) It made no difference whether the conduit was in firm ground, or in soft ground, or carried on a trestle over marshy ground; the result was the same wherever it crossed the fault. In many places where the conduit was carried on trestlework the timber showed considerable decay: Whether sound timber structures would have withstood the shock seems open to question. (See also Pl. X, *A*.)

Within the city proper the reservoir known as Lake Honda was damaged by the cracking of its concrete lining. It is reported that this cracking was due to the displacement of a retaining wall by a sliding bank set in motion by the earthquake.

The distributing mains of the Spring Valley Water Company, passed through soft or made ground, suffered in

same way as the conduits and pipes which crossed the fault line. (See the maps, Pls. LVI and LVII.) Some subaqueous pipe lines crossing the bay seem not to have been injured.

Two interesting earth dams are those at the San Jose Water Company's Saratoga reservoir, which lies in a saddle in the mountains and is retained by an earth dam at either end. The fault runs directly through the reservoir, crossing both dams approximately at right angles. It was reported that near the east end of the north dam transverse cracks were formed, which extended through the body of the dam. There was also a longitudinal crack on top and some settling of the upstream half of the dam. The reservoir seems to have been full at the time of the earthquake, but no evidence was found that any water had escaped through this dam. At the south end of the reservoir the fault line intersected not only the dam but the 10-inch outlet pipe, which was broken by the earthquake. Considerable damage seems to have been done to the dam by the water escaping through this broken outlet pipe. Whether the dam itself would have been seriously injured by the earthquake but for this pipe can not probably be determined.

Professors Marx and Wing also noted in the vicinity of the fault a number of monolithic concrete bridges, all of which were uninjured; none of them, however, absolutely crossed the fault line. (Cf. Pl. XI, A.) These observers also report that a small concrete reservoir, built partly in embankment and partly in excavation, was wrecked by the earthquake, and seem to think that such structures would better be built in excavation. They found that some high timber frames carrying water tanks, as well as similar structures sup-



so that, although it will suffer damage from future earthquakes, this damage will not be at all fatal, and the city will not burn up as a result of it.

DISTRIBUTION SYSTEMS FOR WATERWORKS.

In a city subjected to earthquakes it seems practically impossible to suggest any method of construction which will make the mains and distributing pipes at all times perfectly secure. In my judgment the only remedy is to have within the city itself a large storage capacity, distributed among various reservoirs, and to have a more than ordinarily complete gridiron of mains with gate valves to cut out any main at every intersection. Further, the mains should be larger than would ordinarily be required, so that if a portion of the gridiron were shattered it could be cut out, but the water could be brought in undiminished quantities to the perimeter of the shattered area from all undamaged parts of the gridiron; that is, the mains should be so large that, although the water would have farther to travel in this case, there would be an adequate supply for fighting fire, if necessary, in the area where the mains were shattered.

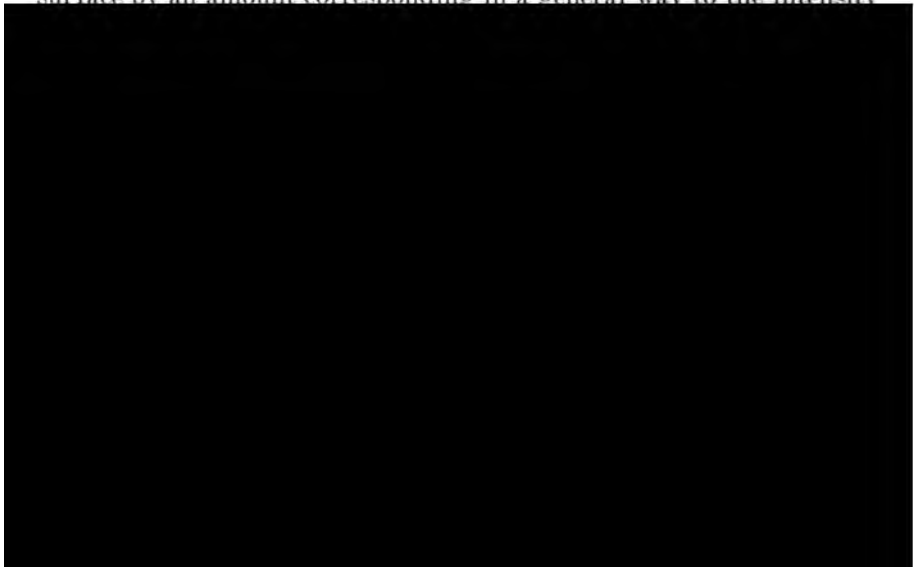
It would seem that in a city like San Francisco a special system of high-pressure salt-water mains, supplied from a pumping station, would be the best solution of the fire-fighting problem so far as the congested district is concerned. This plan has been recommended by the National Board of Fire Underwriters, and it is probably the wisest one under the circumstances. The pumping station should, of course, be protected from earthquake damage in every possible way. Perhaps it should be a floating station. The salt-water mains should be so laid out and so interconnected that nothing short of general destruction of the entire system could wholly shut off the water from any considerable area.

In a city like San Francisco, where there is practically no damage from freezing, it would seem worth while to run the mains exposed everywhere, so that breaks could be located almost immediately. As these breaks would ordinarily occur only in scattered localities, and would not be very great in extent themselves, it ought to be possible to repair them in time to prevent any general destruction of the city by fire. Running the mains exposed would, of course, introduce difficult problems at street crossings, but there is little doubt that such problems could be solved successfully if they were seriously studied. All this means greatly increased expense in the distribution system, but in a situation such as that of San Francisco it seems to be required.

The earthquake effects at San Francisco also indicate clearly that a special study should be made of the problem of promptness in emergency repairs to the conduits and mains. It seems certain that,

in the immediate vicinity of existing faults and near areas including any considerable amount of made ground, both conduits and mains may be expected to suffer serious damage. At one point on Van Ness avenue (see B, Pl. LVI), where I happened to see the mains uncovered, a heavy water pipe, apparently about 20 inches in diameter, had been broken into pieces not more than 2 feet long. The total length of the break, however, was not more than 40 or 50 feet, so far as I could judge from what I saw uncovered. It would seem that this main might have been spliced in a few hours had there been some means of rapidly plugging the broken ends on either side of the break and making a number of taps in the undamaged parts with parallel lengths of fire hose of large size. With gate valves at short intervals it ought to be possible to cut out any damaged portion of the system by connecting through with fire hose in such a way as to maintain at least a partial supply of water for fire-fighting purposes. Some similar plan on a larger scale might be devised for repairing conduits.

It would also seem desirable, wherever an important conduit or main crosses filled ground or material soft enough to suffer consolidation as a result of thorough shaking, to carry the main on piles or other foundations reaching to firm material below. Wherever there was filled ground the vibration due to the earthquake seemed to have much the same effect as would be produced in a vessel that had been loosely filled with sand and then subjected to vibration; as is well known, the sand, under such circumstances, will suffer consolidation to a very appreciable extent, which naturally lowers its surface by an amount corresponding in a general way to the intensity



under pressure, and therefore can not be repaired with fire hose, as suggested for water mains. There seemed to be some fear in San Francisco that the breaking of the sewers and the water mains would cause the water to be contaminated by the sewage; but evidently if means were devised to maintain a good pressure in the water pipes this pressure in itself would protect a leaky main from such contamination.

FIRE-RESISTING FEATURES OF BUILDINGS IN "CONGESTED DISTRICTS."

FIREPROOFING.

The Baltimore and San Francisco fires, as well as many other fires and fire tests, have proved conclusively that commercial methods of fireproofing are inadequate to stand any severe test. In most buildings the steel work is fairly well protected, but the number of failures is sufficiently great to show that the factor of safety against fire is not by any means what it should be.

For the protective covering itself to suffer complete destruction, or almost complete destruction, in any one fire is in itself a failure, because under such circumstances the steel work is very near destruction and the margin of safety is altogether too small. It is more than probable—almost certain, in fact—that a detailed investigation of all the buildings in San Francisco would reveal many "protected" columns, not indicated in this report, that buckled as a result of the failure of the covering. In my judgment, columns should either be covered with 4 inches of brickwork, laid in Portland-cement mortar, and have all of the interior space filled with concrete, or else they should be inclosed in an expanded-metal jacket and the entire interior filled with concrete, so that the minimum thickness of the concrete would not be less than 4 inches. Exposed flanges of girders and beams should be protected by the equivalent of $1\frac{1}{2}$ to $2\frac{1}{2}$ inches of solid porous terra cotta, according to circumstances. If concrete is to be used, this thickness should be increased by about half an inch. The protection for lower flanges should always be inclosed in a basket of expanded metal or heavy wire lath, securely anchored into the side protection of the webs. The San Francisco experience showed that, even in a hot fire, such metal-mesh basket work will largely retain its tensile strength, and thus hold in position the fireproof covering inside even though the latter should be shattered by expansion stresses or otherwise. The webs of the girders should be covered by 4 inches of brickwork or concrete, built up on the lower flanges. Girders should be completely covered from bottom to top before the floor systems are put in, so that the collapse of the latter will not expose the girder. Floor beams should have heavy, solid protecting

skew backs, not less than $1\frac{1}{2}$ inches thick, or be covered with at least 2 inches of concrete. In an important work the protection of the lower flanges of the floor beams should also be incased in expanded metal or wire lath. The furred ceilings so much used in San Francisco are a valuable addition to the fire-resisting qualities of floor construction, and if the furring rods were more firmly secured the total loss here, as a rule, would be measured by the value of the plaster alone.

Hollow-tile partitions should not be less than 6 inches thick. The tiles should have webs at least 1 inch thick, and all interior angles should be well filleted. The tiles themselves should be carefully laid in Portland-cement mortar, with all joints absolutely filled. Timber studs running to the top of the partition, to frame a door or window opening, should be absolutely prohibited. The webs of floor tiles should not be less than an inch thick, and their interior angles also should be well filleted.

The results at Baltimore and San Francisco did not, by any means, indicate that either hollow tile or concrete is altogether a failure or altogether a success. Both fires indicated very clearly that commercial methods of applying both materials are inadequate, but also that successful results can be attained with both materials.

A conflagration never yields reliable comparative results, but judging from such comparative results as are available, I think that there is no question that the best fire-resisting material available at the present time is the right kind of burned clay—that is, a good, tough, refractory clay, almost as refractory as fire clay, made into proper shapes and properly burned. Some commercial hollow-tile



was before; whereas concrete of any kind which has come through a fire in which the temperature has exceeded 700° or 800° F. is inevitably damaged in all cases, owing to the dehydration of the cement, although it may appear uninjured to the casual observer. This property of concrete, of maintaining a good face in spite of real and serious damage, is likely to lead the layman into dangerous conclusions, and consequently into equally dangerous practice. It would seem that wherever reenforced-concrete floor construction is used a furred ceiling below it should be absolutely required.

The furred ceilings ordinarily used are too light; the furring rods are not quite heavy enough and they are not adequately secured to the floor construction above. If they were made a little heavier, and were more firmly secured, it is probable that, as a rule, no loss would occur except that of the plaster. Even if the furred ceiling comes down bodily, this failure is not apt to occur until so late a stage in the fire that the floor construction above will be practically undamaged, because there will not be enough left of the fire to raise the temperature of the concrete to the point where dehydration of the cement will begin. The presence of a furred ceiling, however, no matter how good, should never be accepted as an excuse for omitting the protection of the lower flanges of the floor beams and girders. A hollow-tile floor that would be fully equivalent to a reenforced-concrete floor, with a furred ceiling, could be made by using tiles in which the minimum thickness of the webs is 1 inch, and of which the material itself is tough, refractory clay, made porous by the addition of sawdust; such tiles should, however, be burned to a point where the clay itself is just short of vitrification. All the interior angles, where the webs of the tiles join each other, should be rounded to a radius of at least 1 inch or 1½ inches. If necessary to secure proper burning, a small hole three-eighths to five-eighths of an inch in diameter might be allowed through the mass of clay at the intersection of the webs.

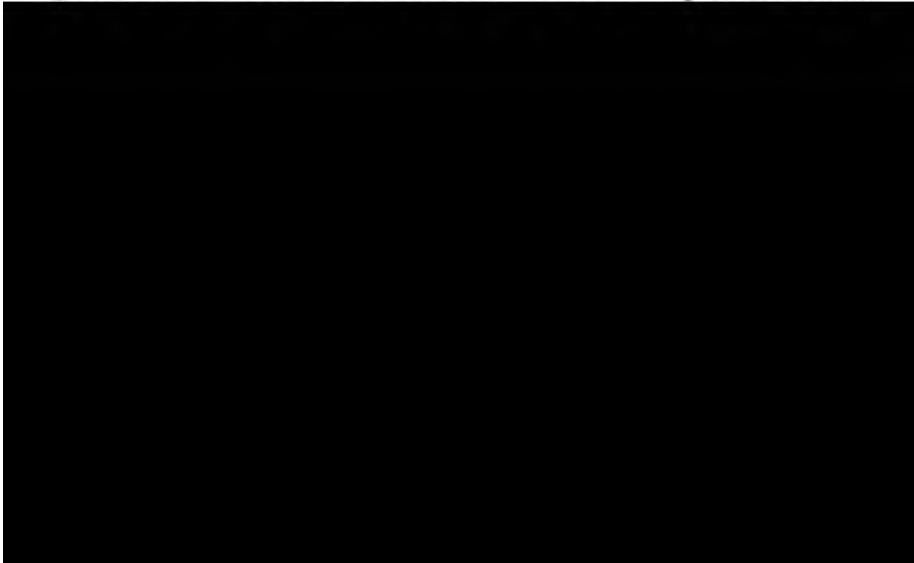
Tests recently made of a pattern of tile used at the War College indicate that floor tiles subjected to a fire test will stand better if there is but one interior hole through the tiles, all the material which would otherwise be used in the interior webs being concentrated in the outer webs, and the opening in the tile being of circular or elliptical shape, depending on the height and width of the tile. For floor arches between steel beams such a tile as this one would have to be used on the end-construction plan. A specially heavy skew back should be designed to go with it, or else the end tiles should be cut to fit the profiles of the beam. The tiles themselves being so heavy, the latter method of obtaining a skew back would probably make the arch more than strong enough to carry its load, and where

although for that purpose a specially designed extra heavy side-construction skew back would be better, and should on the whole be recommended even in connection with the heavy end-construction arches described. It is probable that either a good concrete floor with the right kind of ceiling below it, or a heavy tile floor such as that herein described, would come through almost any fire with no damage except the loss of the ceiling plaster. These two types may therefore be taken as equivalent in efficiency; they will probably be about equal, also, in first cost.

It should be added that attic floors and roofs should be as carefully designed to resist fire as any other part of a building. This is a thing that has rarely been done, and the experience of both Baltimore and San Francisco shows that it is absolutely necessary.

PROTECTION OF OPENINGS.

While there is no doubt that commercial standards of fireproofing are dangerously inadequate, the greatest trouble of all is the fact that so little attention is paid to protecting the exterior openings in a building. Even a very inefficient type of fire shutter would probably have saved some of the buildings in San Francisco, which were, as a matter of fact, burned out. A light metal shutter combined with a window sprinkler would probably resist a rather fierce fire for a long time. Although the failure of the water supply in San Francisco might be urged as one reason why a window sprinkler would have been of no avail, it is a fact that water can be obtained by driving wells into the sand which underlies the business portion of San



the sheet of steel is itself in position. By providing a pocket in the masonry just above the window head and making these shutters in three or four parts, overlapping and interlocking at the overlap, the whole shutter could be slid up into the wall practically out of sight. This arrangement would necessitate window openings slightly lower than those used in many commercial buildings, but the loss of light would not be very serious. The metal shutters when closed should overlap the window opening in all directions by at least 6 inches. This overlapping could be accomplished at the sill without making a pocket to catch water and dust, by forming a step in the sill itself.

2. The windows should be made entirely of wire glass, with sheet metal or metal-covered sash, hung in metal or metal-covered frames. Clear wire glass can be used if desired.

3. On the inside of the window there should be a sliding shutter, either of wood covered with sheet metal or of sheet metal such as that described for the outside. If the outer wall is furred, a pocket could be made between the furring and the wall, so that the inside shutters could be slid sidewise.

It is probable that under a fairly bad exposure to fire the outer shutters here described would be so damaged that they would have to be removed. In a conflagration they would probably be warped to such an extent as to let the heat in, and possibly to soften the wire glass and damage the windows themselves, so that they also might have to be renewed—at least so far as the sash were concerned. But it is very doubtful if any conflagration would ever get through the sash, much less through the inside shutters. Any damage to the window protection, however, would be a very small matter compared with the total destruction of the contents of the building and a damage of 65 to 80 per cent to the building itself.

Window protection of the kind just described could be so designed that it would not be objectionable even on the principal fronts of buildings. The San Francisco and Baltimore fires have demonstrated that all the exterior openings of even fireproof buildings need protection. It would seem that the time has arrived when building ordinances should require it.

If to the triple window protection described above a window sprinkler with adequate water supply is added, a defense which will probably not only be adequate for its purpose, but which will suffer small damage itself, will be provided. This system of protection, while it has never been applied, can be applied at a cost which is not prohibitive, especially if unnecessary and expensive finish is omitted.

Practically all the fireproof buildings in San Francisco were unshuttered. Many nonfireproof buildings were partially shuttered,

graph Company on Bush street, was completely shuttered. Although every opening in this building was protected, it is not certain that the fire did not find its way into the building through some of them in spite of the protection. The protection of individual openings apparently was not quite heavy enough.^a

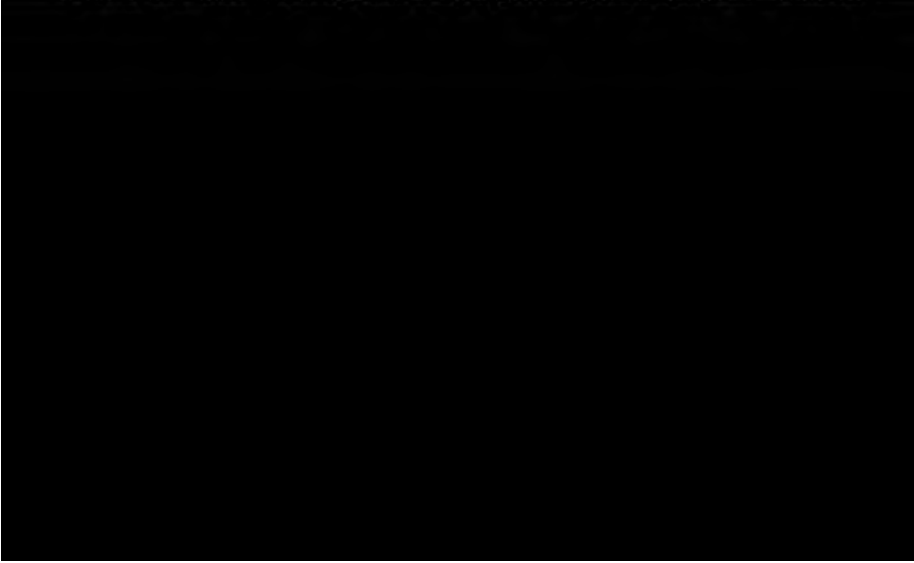
The view of the main front of this building (Pl. XLI, A) shows plainly that it was not severely attacked by the flames, yet it probably would have resisted such an attack a good deal better than the façades of many other buildings. The exterior architraves of most of the windows are of solid molded brickwork, and the amount of hollow terra cotta in the exterior front is reduced to a minimum, so that this building would probably not have suffered quite as much as the average, even if the fire test from the outside had been fully as severe.

FIREPROOF VAULTS.

It would seem that the question of so-called fireproof vaults in commercial office buildings should also receive some attention. The failure of such vaults in San Francisco is absolutely inexcusable. The fact that they were so flimsy was not due to any lack of available knowledge as to how a fireproof vault should be built; the only motive that can be imagined for the erection of such vaults is parsimonious and criminal economy. (See Pl. LII.)

CONSTRUCTIONS AND MATERIALS RECOMMENDED FOR EARTHQUAKE LOCALITIES.

For every tall building the best type of construction is undoubt-



edly saved the masonry. In such buildings as the new Chronicle and the Monadnock the effect of the vibration was really resisted by the masonry, which was much shattered. Some of it was precipitated into the street from the new Chronicle Building, the Rialto Building, and others. It is not at all certain that the steel frames of these buildings have not also been seriously damaged by the earthquake. Naked steel frames of the same type came through without serious damage, but they did not suffer the additional stresses due to the vibration of a great load of masonry, floor construction, and contents in the upper stories, as did the finished buildings. It is not right to run the risk of precipitating the masonry into the street on the heads of passers-by, as would have happened at the unbraced steel-frame buildings had the earthquake occurred at a later hour in the day. Besides, if the strength of the building is dependent on the masonry, which is seriously shattered by the stresses that it is expected to resist, the factor of safety against general collapse is manifestly too small. The steel-frame construction should therefore be thoroughly braced. In my judgment, to obtain the best results it should also be inclosed with walls of reenforced concrete, in which case it would be almost impossible to throw the walls off. The proper artistic treatment of this material in a place like San Francisco would seem to be a very important problem for the architects. The great utility of reenforced concrete in earthquake shocks can not be denied. Where steel-frame buildings are to be finished with ordinary masonry walls, however, complete bonding of all face bricks with full header courses should be absolutely required. No other form of bond is adequate. Nothing but Portland-cement mortar should be allowed in any part of the structure. The masonry should be tied to the steel frame in the very best possible way, and much more securely than is ordinarily the case.

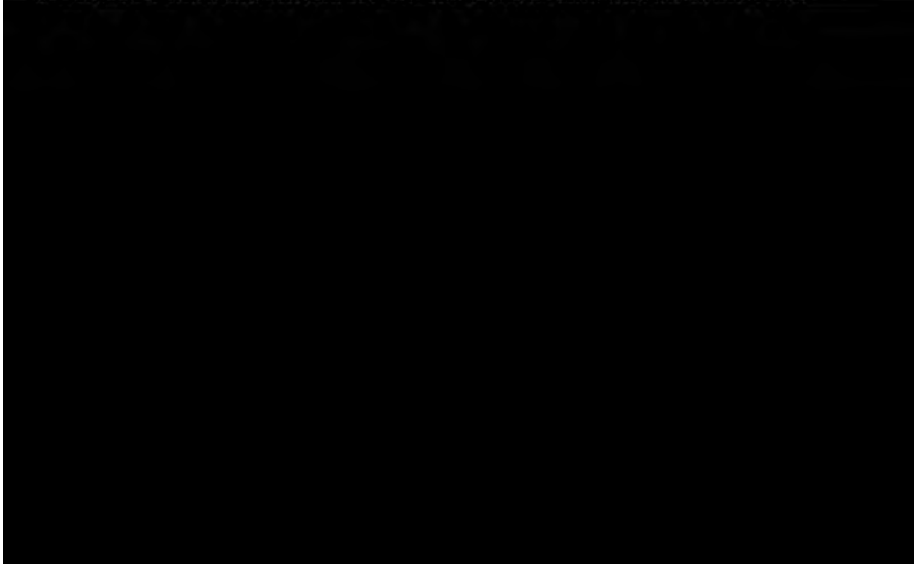
For buildings of moderate height, say up to 125 feet as an extreme limit, reenforced concrete alone can undoubtedly be so designed as to give very good results when subjected to either earthquake or fire. But the bracing of a reenforced-concrete building of any height to resist earthquake is a matter for serious study. The problem can be solved, but it has not been solved yet.

Any building of considerable height, in an earthquake country, should have as little mass in the superstructure as possible, consistent with other necessary qualities. But this limiting of mass does not mean that the flimsy floors and partitions heretofore in use should be continued. In fact, to make the buildings proof against both earthquake and fire it is probable that they will have to be at least as heavy as they have been, but changes in distribution of the mass could advantageously be made.

For the ordinary commercial building, where brick walls and wooden joists would ordinarily be used, I am of the opinion that the use of reinforced concrete would be the safest and most practicable solution in a place like San Francisco. Where reinforced concrete is used throughout, whether the building is very tall or not, great care should be taken with the design and execution of the connections between the columns and the members of the floor system. There should be heavy knee braces for the connection of all girders and beams, and, wherever possible, portal bracing in the shape of reinforced-concrete arches should be introduced. Of course the amount of this work that needs to be done depends on the circumstances in each individual case, such as the height of the building, its horizontal area, the kind of material, the dead weight in the upper stories, etc.

The opposition of the bricklayers' union and similar organizations has hitherto prevented the use of reinforced concrete in San Francisco for all parts of buildings. This action of the labor unions has probably cost the city a good deal, and, should it be continued, will cost a great deal more in the future.

From the effect on the fortifications, and on monolithic and massive concrete structures elsewhere, as indicated by the details taken from the report of Professors Marx and Wing, it seems justifiable to conclude that a solid monolithic concrete structure of any sort is secure against serious damage in any earthquake country, unless it should happen to lie across the line of the slip; in that case the damage might be fatal, or it might not, depending altogether on the amount of the slip and the intensity of the forces that accompanied it.



more than the structure itself, especially if any attempt is made to fix the value of records and papers that can not be duplicated. In the second place, the buildings themselves suffered a damage exceeding 65 per cent, and in San Francisco probably amounting to almost 80 per cent. A study of the items entering into this damage discloses the fact that a very large proportion of it is due to the loss of the architectural finish, such as face brickwork, ornamental terra cotta, and stonework on the exterior; marble dadoes, columns, and other finish on the interior; wooden door and window frames, wooden doors and windows, ornamental grillwork, etc. If the fireproof-building problem is to be solved in such a manner that conflagrations will not cause serious losses, it would seem that radical revision of the method of finish is necessary. As the finish must practically be a total loss anyway, it should be so devised that it can be replaced at small expense. This requirement, however, makes it impossible to adopt a material for the construction which, as the architects say, finishes itself—because, if the exposed surface is destroyed, the material becomes a total loss. It would seem that for the exterior of the structure, walls well built of good, common brick, laid in Portland-cement mortar, or else of reenforced concrete, could be finished on the outside with stucco, pebble dash, or some similar material. The opportunity for the effective use of colors here would be very great. If the buildings were exposed to a fire, the exterior finish would probably be a total loss, but its value in dollars and cents is small. The fire might even strip it off and cause serious spalling to the main wall underneath, but, even so, the operation of renewing the finish would furnish adequate repairs for the main wall itself. On the other hand, if face brick or stone or ornamental terra cotta be spalled, the loss is total; the original finish can not be renewed, except by tearing the wall down and rebuilding it. On the interior, combustible trim of all kinds should be eliminated and marble or stone finish should be securely protected from the access of fire. Enameled bricks and enameled tiles should also be made secure against not only the direct access of fire but the effects of high temperatures however applied. Instead of marble wall finish or enameled bricks or tiles, wall plaster of a good quality, finished with enamel paint, furnishes a perfectly satisfactory substitute, so far as utility and sanitary qualities are concerned. If such finish is destroyed by fire, its renewal is a matter of relatively small cost.

All interior partitions should be so solidly constructed that there would be no question whatever of a fire ever getting through them. That ought to be absolutely impossible. Stairways, stairway halls, and other places where elevator grills, ornamental balustrades, etc., might be used should be so located that no fire would ever get into
2 uly free of combustible m

of all sorts and descriptions. Wooden floor finish should not be allowed in any portion of the building. All doors, door frames, window frames, and window sash should be of metal or of wood covered with metal. All important openings should have doors on both sides of the wall, the idea being to so design the interior of the building that a fire starting in any one room could be left to burn itself out not only without being communicated to other rooms or to the corridors, but also without causing any great money loss to the building itself in the room or rooms where the fire occurs. The interior construction of the building should be such that, should a fire by any chance be introduced from the outside, it could be confined absolutely to the room or rooms to which it finds access. Such a thing as a conflagration sweeping through a building can be made impossible at reasonable expense, provided unnecessary architectural finish is omitted and the money ordinarily expended on it is applied to other things. -

Even such a building, however, might have a shutter left partly open, or some other of the various fire-resisting devices might be left in such condition as to defeat the purpose for which it was installed: so that if the building contains a large amount of combustible contents, it should still be provided with sprinklers. The municipal water supply should be under sufficient pressure to supply the sprinkler system. In a city like San Francisco an artesian well and fire pump in each building should be provided for the same purpose, if possible. Even then, if there is a conflagration raging, the mechanical staff of the building and as many more men as can be obtained should be kept on duty inside the building, watching for



A fire-resisting building is, in one sense, exactly analogous to a fortification—it needs a garrison to make it thoroughly effective. There is this difference, however, that a fire-resisting building can be made so effective in itself that a relatively small garrison can save it. In my judgment, a building thoroughly well constructed along the lines indicated in this report would stand in a conflagration such as that which occurred in San Francisco, preserve its contents, and suffer a loss to its own structure and finish not exceeding 15 per cent. Until a result approximating this degree of endurance is achieved, it is hardly fair to say that the “modern fire-resisting building” is a success, except in so far as it enables a sufficiently tall structure to be erected on a piece of valuable real estate to furnish an adequate return for the entire investment, and even this statement is true only as long as the building does not happen to be attacked by a conflagration.

EARTHQUAKE INSURANCE.

It would seem that in a place like San Francisco it would be sound policy for the business men to form a mutual earthquake insurance company on lines similar to those of the mutual fire insurance companies. They should employ competent experts to draft specifications and evolve types of designs not in conflict with the municipal ordinances for buildings specially planned to resist earthquake. To be admitted to the benefits of the mutual earthquake insurance company an owner should be required to conform to the standard plans and specifications. In my judgment, there is every reason to believe that such an enterprise could be made successful and that it would result in having available at all times a fund for making good any earthquake damage. It is probable that the premiums that would have to be charged by such a mutual insurance company would be found to be no greater than those that are charged for fire risks in large cities.

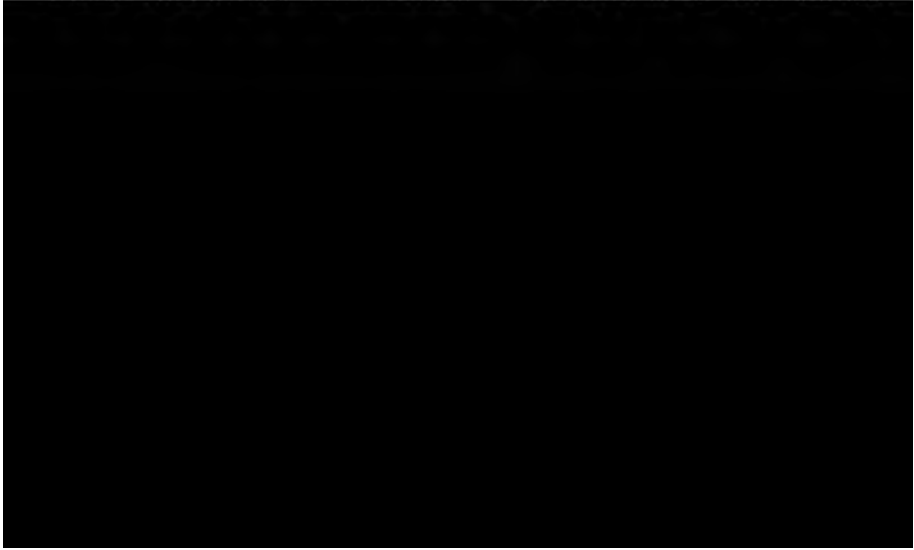
SUMMARY.

It will be apparent that much of the information presented in a report like this one is necessarily hearsay. So far as the history of the fire is concerned, this indefiniteness can not be avoided, and the details of the damage itself could be verified only by a prolonged stay in the ruined city and a close inspection of the ruins of every building at every stage of the process of cleaning up. It is to be hoped that the technical men engaged on this work will keep a complete and accurate record of all details of every sort, which will be available for future reference. It is believed, however, that enough evidence was collected at first hand to abundantly justify every con-

clusion and broad statement contained in this report. The only doubt in my mind is whether the damage may not have been really greater than it appears.

Extreme caution should be observed in drawing general conclusions from any individual case of damage in a great conflagration. For instance, the way in which misleading conclusions can readily be reached is indicated in the discussion of the relative merits of terra cotta and concrete for fireproof floor construction. The records of the fire, rightly read, would prove that both concrete and burned clay are efficient as materials, but that the method of application of both is open to severe criticism. That hasty and ill-founded conclusions have been reached is only too evident from the articles which have appeared since the San Francisco disaster.

It is also necessary that extreme caution should be observed in drawing conclusions in regard to the effect of the earthquake. Reenforced concrete proved itself superior to brickwork beyond any doubt. There is every reason to believe that for buildings of moderate height reinforced concrete can be so designed that it will be quite as efficient as a steel frame; but it should be remembered that this proposition was not proved, because there was no reenforced-concrete building of considerable height in the entire district affected. Again, the fact that steel frames stood up during the earthquake does not prove that they are earthquake proof. The framing of the tower of the Union Ferry Building suffered almost fatal damage, yet it stood up. The Call Building proved the efficiency of stiff and adequate steel bracing; but many of the other commercial steel-skeleton buildings showed very clearly the need of it. The fact that some of the tall



THE EARTHQUAKE AND FIRE AND THEIR EFFECTS ON STRUCTURAL STEEL AND STEEL-FRAME BUILDINGS.

By FRANK SOULÉ.

THE EARTHQUAKE.

GEOLOGIC FEATURES.

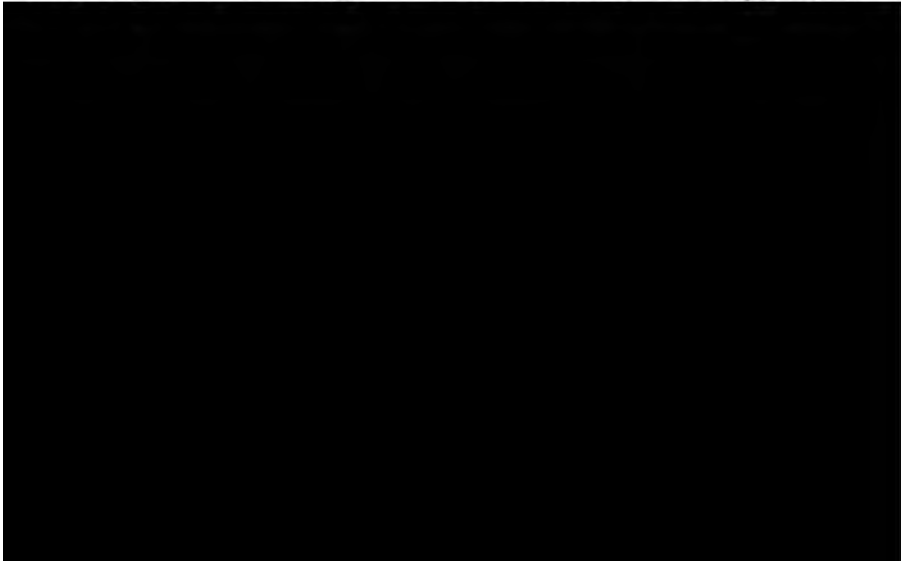
On the morning of April 18, 1906, central California experienced an earthquake, the most severe, as measured by its results, in the history of the State. The seismograph in the observatory of the University of California, at Berkeley, recorded the shock as beginning at 5 hours 12 minutes 6 seconds a. m., Pacific standard time, and as lasting for one minute and five seconds. Its severity was afterwards estimated and rated as IX in the Rossi-Forel scale of earthquake intensities. Other minor shocks followed immediately and at short intervals, so that before 7 p. m. of the same day thirty-one of these had been registered at the observatory. Slight shocks, coming successively after longer and longer intervals of time, were experienced during several weeks following, until finally the earth's crust in California seemed to have readjusted itself to new conditions of pressure and equilibrium. The material damage from the earth tremors was inflicted by the first great shock. The minor ones following wrought no injury, except to throw down a few tottering walls that had been racked by the original earthquake.

For many years the leading geologists in California have known that a rift, or line of dislocation in the earth's crust—called in common parlance an "earthquake crack"—starting near Point Arena, extends in a straight line, at least 400 miles in length, in a direction S. 35° E. (fig. 1, p. 3). Passing under the ocean bed 8 miles west of the Golden Gate, the rift cuts the shore again at Mussel Rock, runs along the reservoir basins of the Spring Valley Water Company and over the Coast Range of mountains, ignoring surface topography in its course, and extends at least to Mount Pinos, in Ventura County, and probably still farther to Lake Elsinore, in southern California. This great "fault" gives abundant geologic evidence of having been, in the remote past, the locus of many distinct earthquake movements and disturbances.

It was a rupture and slip along this fault, plainly evident for nearly 200 miles, that shook so violently the thousands of square miles of the earth's surface in central California. The first snap and movement of the crust were registered at the observatory of the State University as proceeding from south-southeast to north-north-west, or about parallel to the fault. This movement was there recorded as over 3 inches horizontally, and was accomplished, as estimated by the California earthquake investigation commission, in one second of time. The vertical movement at the same place and time was believed to be about 1 inch. Professor Omori, the distinguished Japanese seismologist, also estimated the vibration in San Francisco to be 3 inches in one second.

Instantly following this first snap were rebounds, reactions, and terranean reverberations from all parts of the greatly disturbed area on either side of the fault trace, which made the record on the seismograph resemble a tangled spider's web. It was this part of the earthquake—the temblors—that created and continued the racking vibrations, the twistings, and the wrenchings that brought down chimneys, walls, and towers.

Members of the California earthquake investigation commission advanced the belief that the first break, slip, and shock in the crust began at the northwest extremity of the fault trace, and that from this point the rupture and shearing extended progressively toward the southeast. This view seems to be borne out by later investigations, and certainly the greatest disturbances on the line of the fault were at and near its northern extremity. The earthquake was felt to a greater or less degree over a vast extent of territory, stretch-



twisted, and thrown down (Pl. X, *B*); fissures were opened in the earth (Pls. III, IV); trees were uprooted and thrown to the ground, or snapped off, leaving their stumps in a standing position, or split from the ground up through the stock to the branches (Pl. II). Roads were ruined for long distances, bridges were thrown off their abutments (Pl. XI, *A*), and water pipes were twisted, telescoped, collapsed, or broken (Pls. IX; X, *A*). Along the seashore immense landslides occurred, throwing vast quantities of earth and rock into the sea. (See also Pl. VIII, *B*.)

The main pipe lines of the Spring Valley Water Company, which were depended on exclusively to supply the city of San Francisco with water, as well as the distribution system of this company in the city, were broken in many places, and the supply of water was absolutely cut off for a number of days after the earthquake (map Pl. LVI). The great mains leading from Pilarcitos, San Andreas, and Crystal Springs lakes were all badly broken (Pl. LVII). The Pilarcitos conduit in particular, which ran almost along the fault trace, was completely ruined and rendered unfit for repair (Pl. IX). The great 44-inch water main crossing the San Bruno marsh was thrown down from its supporting trestles in a serpentine line, and broken in several places.

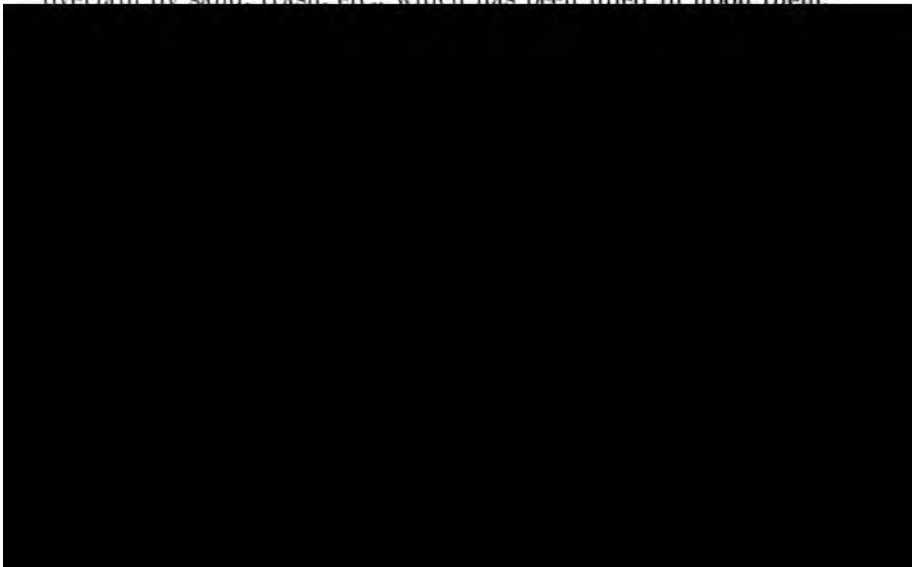
As the distance from the fault trace increased, the violence of the disturbance in a general way diminished, but this statement must be modified by saying that in cities and towns built upon the alluvial soil of valleys the destruction was at its greatest, as, for instance, at Santa Rosa, about 20 miles east of the fault trace, in the Sonoma Valley (Pls. XIV, *B*; XVII, *A*). This city, built upon a deep, alluvial soil, was more severely shaken and suffered greater damage, in proportion to its size, than any other town in the State. Scarcely a brick or stone building in the town was left standing, and 80 people were killed.

SOIL FORMATION.

The destruction wrought by the earthquake amounted to little or nothing in well-built structures resting upon solid rock, and, all other things being equal, increased in proportion to the depth and incoherent quality of the foundation soil. Thus dwellings in Berkeley, upon the solid rock, were scarcely disturbed, while those on the level plain of Oakland, 4 miles distant, were severely shaken and injured, as, also, were the buildings at Leland Stanford Junior University (Pls. XIV, *A*; XV; XVI; XVII, *B*; XVIII), 7 miles distant from the fault trace; at San Jose (Pls. XII, *B*; XIII, *B*), 13 miles distant; and at Agnew (Pl. XIII, *A*), 12 miles distant. The town of Salinas and the alluvial valley of Salinas River were also severely shaken. This region was fissured and disturbed more than

In order to get a fair understanding of the effects of the earthquake in San Francisco, a knowledge of the geologic formation and the different soils constituting the foundations of structures is necessary. The city and county of San Francisco comprise the northern extremity of a long, narrow peninsula, lying south of the Golden Gate, between the Pacific Ocean on the west and the southern half of San Francisco Bay on the east. (See map, Pl. LVII.) The boundary line between this county and San Mateo County lies about 8 miles south of the Golden Gate. The area of San Francisco County is $46\frac{1}{2}$ square miles. The population of the city on April 1, 1906, was estimated to be 460,000.

The site of the city has at least four different soil formations. Around the Bay of San Francisco, from Telegraph Hill to Mission Creek, which runs from west to east and empties into the bay, and on both shores of the creek is a strip which was originally mud flats and overflowed lands, having an area of about 354 acres. These tracts have been gradually filled in (especially on the bay shore and the northern Mission Creek sides), since the days of the American occupation, by encroachments on the water front, due to business and commercial pressure, and wharves and docks, warehouses, factories, manufacturing establishments, and large wholesale houses have been built on these filled-in lands. At the present time these large areas are for the most part included within the sea walls running around the officially established water front nearly as far as Mission Creek. They are known as "made lands," and consist of deep layers of mud, in many places saturated with salt water, and overlain by sand, trash, etc., which has been filled in upon them.



the city are closely built residence districts, and the areas toward the Pacific Ocean are covered with cottages, more and more sparsely placed, to the boundaries of the county.

Adjoining the business district on the southwest side, along Mission Creek, on the flat sand lots, was another thickly populated residence section known as "south of Market street." It was occupied almost exclusively by wooden buildings.

More than 90 per cent of the buildings in San Francisco were of wood. Almost all the brick, stone, and steel structures were in the congested business portions of the city, upon or very near the made land. Even in this district there was a large percentage of wooden buildings. High steel structures of the most modern type have been erected only recently in San Francisco, and the number of them is small, not exceeding 50.

The most destructive effects of the earthquake in San Francisco were experienced upon this made land. Wherever buildings were well founded on wooden piles deeply driven into the mud—as, for example, the Union Ferry Building—these foundations were disturbed but little or not at all; and where the superstructure had been well and strongly put up, practically no damage resulted. Only in poor foundations laid directly upon "filled-in" ground on the raft principle, or in buildings that were poorly constructed or underpinned or had a weak frame, poor brickwork, or brick laid dry in poor lime mortar, was there serious damage or collapse.

The Union Ferry Building (Pl. XLVI, *A*), with the exception of its high tower, was little injured, and the level of its floors was not perceptibly changed. At the same time, the streets at its front, which rested simply on the made soil, were rolled into waves 3 or 4 feet in height. So far as the writer is aware no foundations that had been properly established were in any considerable degree injured by the earthquake; nor was any structure of brick or stone, iron or steel, that was well designed and constructed, greatly damaged. Some chimneys and cornices were thrown down, but until the fire had passed over the region the structures remained ready for use. This statement applies especially to the wooden-frame structures throughout the residence part of the city, where the only losses were those of chimneys and plaster.

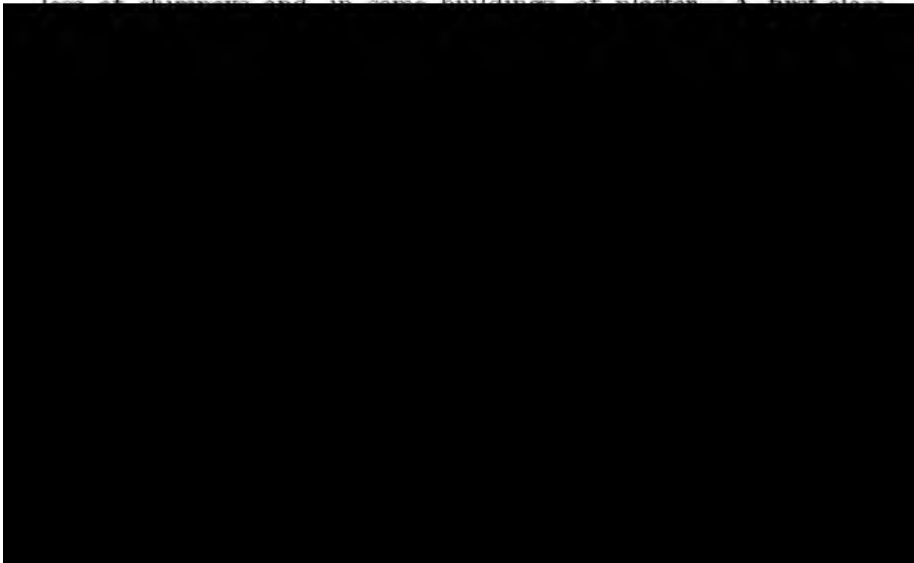
On the made land in the business portion of the city there had been erected in early days many light wooden buildings, which rested on simple timber underpinning founded on the filled-in material. Many of these structures collapsed, but this result was due to their imperfect foundations and weak construction rather than to the severity of the earthquake. Numerous structures in this district had been built of dry brick or stone laid in common lime mortar,

and many had not been anchored.

walls. Such walls commonly collapsed, and the brick were found afterwards with dry, clean surfaces, the mortar having no adhesion. (See Pl. XXI, A.) On the other hand, walls that had been laid in Portland-cement mortar, with brick thoroughly wetted and all parts well bonded together, stood the trial perfectly and are standing to-day.

Tall, steel-frame, stone-exterior office buildings of the class A type that were founded either on well-driven piles or on concrete slabs suffered no very serious injury by the earthquake. With the exception of a crack here and there in a stone pier, arch, or stairway, or a block of veneer loosened or dropped from a front, they remained entirely serviceable, so far as the earthquake effect was concerned. An excellent example of this class of buildings, and one that is exceedingly instructive, as it passed through the earthquake but escaped the fire that ravaged San Francisco, is the Union Savings Bank, in Oakland, at the corner of Broadway and Thirteenth street. This building is a steel-frame, stone-veneered structure, having 11 stories and a basement. It is founded upon separate concrete blocks and piers which rest upon a strong soil of mixed sand and clay. This structure was practically uninjured.

Buildings in San Francisco which rested upon foundations of sand in natural place were not injured by the shock, except where the sand was on a hillside or had opportunity to spread and flow. In such places buildings of either masonry or wood were badly shaken. Where the buildings rested upon good, hard soil, as on the hillsides or summits, practically no injury was done with the exception of the loss of chimney and in some buildings of plaster. A first class



The death of Mr. Sullivan, the chief of the fire department, which was caused by the falling of a mass of brick from a chimney while he lay ill in bed, was a most unfortunate accident, as the city was thereby deprived of his excellent knowledge and skill as a fire fighter. The fire department, although it responded promptly to the calls and was composed of brave and efficient men, with excellent apparatus, was disconcerted by the loss of its chief and paralyzed in its action by the almost complete rupture and disintegration of the water system. The city mains were so thoroughly broken that in a short time not only could no water be obtained for the extinguishment of fires, but for a number of days little water could be had for domestic use, and the people were compelled to rely on a few wells that remained available.

In private dwellings incipient fires were quickly extinguished by individual effort; but, because of the early hour, the fires which started in the great downtown business houses, factories, etc., "south of Market street," grew to alarming proportions before anyone could reach and conquer them. With the exception of the private water supplies, such as wells (see map, Pl. LVI), pumping systems, etc., possessed by a few establishments, there were no means of extinguishment. Within three hours after the earthquake nine fires were in full conflagration between "The Mission"^a and the water front south of Market street. At first there was little or no wind to fan the flames, but the great heat soon drew in a current of air which continually increased, and, varying from one point to another, swept the flames first in this direction and then in that. By Wednesday noon the fire had consumed nearly a square mile of the city on the south side of Market street, and on the afternoon of the same day it broke across to the north side, in the vicinity of the high steel Call (Claus Spreckels), Examiner, and Chronicle buildings. Thence the fire veered with the wind, burning northward and westward through Chinatown, and joined its destructive energy with that of a separate column of fire that had swept up from the lower end of Market street and the water front. The column, driven by the wind, ate its way rapidly through the residence portion of the city, which was built of wood and hence was consumed like tinder. Three hours after the conflagration had begun a corps of dynamiters was organized, but as no such body had existed in the fire department, it was necessarily composed of volunteers and amateurs. These men fought the flames with great bravery, but with little skill, and their endeavors to arrest the progress of the fire by throwing structures down in its path were

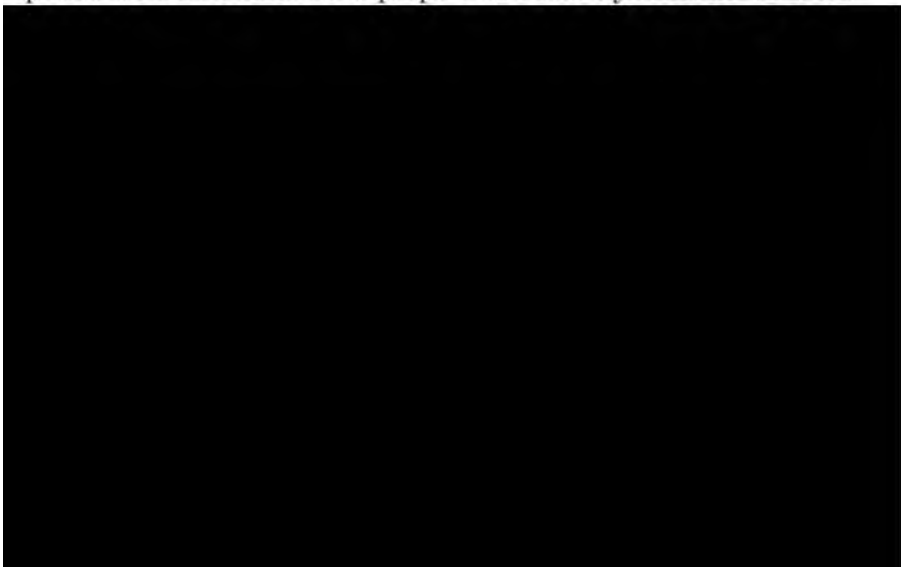
^a "The Mission" is a well-known locality in the city of San Francisco. It is the site of the original settlement and mission established by the Franciscan monks, and the old Mission Church still stands there (Pl. XXIII, B), as the fire was checked at this point just in time to save it.

futile until late on Thursday night, after a dynamite expert had been put in charge. A last stand was made in the western part of the city, at the broad and open street, Van Ness avenue. Here the dynamiters, aided by the shifting of the wind to the west, were able to stay the progress of the fire. Everything in the Mission district had been burned, except at places where the flames were checked by means of private water supplies. Although comparatively feeble, the fire continued in some parts of the desolated district until Saturday morning, April 22, when the last blaze was extinguished. The wharves and a fringe of buildings along the water front had been saved by means of engines and State fire boats drawing water from the bay.

The area of the burned district (see Pl. LVI) is 4.05 square miles, or 2,593 acres, and includes 490 blocks entirely burned and 32 blocks partially burned. These blocks were in two different classes, one being the "100-vara" block," and the other the "50-vara." Some structures along Mission Creek and a few residences on the summits of Telegraph, Russian, and Clay Street hills (Pl. LIV) escaped. The mint and a few other buildings were also saved by means of private water supplies.

Thus the greatest fire in the history of the world destroyed more than 4 square miles of closely built city property estimated at \$500,000,000, half of which was insured; with the loss, it is believed, of about 800 human lives (though the official count is less).

San Francisco was little prepared to fight a conflagration under the existing conditions. Ever since the six devastating fires of the period from 1849 to 1852 the people had evidently relied on the excel-



by the fire owe their desolation for the most part to their environment by these inflammable buildings.

There was no dynamiting corps in the fire department and no adequate salt-water system for fighting fires, although the city was almost surrounded by salt water, and there were no fire boats belonging to the department, and few cisterns in the streets or squares. Most of the streets were very narrow, and many of them were lined by high wooden buildings. With the water mains and distribution system incapacitated by the earthquake, it is no wonder that the city burned; the only wonder is that it had not burned before. This result had been prophesied by insurance inspectors many months previously.

**ABSTRACT OF REPORT OF ENGINEERS' COMMITTEE OF THE
NATIONAL BOARD OF FIRE UNDERWRITERS.**

The Coast Review, an insurance paper, gives an abstract of the report and conclusions of the engineers' committee of the National Board of Fire Underwriters. This report was published in October, 1905, many months preceding the occurrence of the great fire, and is epitomized as follows:

The area of San Francisco within the "fire limits" was 1.6 square miles. The "brick district" comprehended 0.95 square mile, and the "congested-value district" 0.49 square mile. The number of fires in the preceding nine years was moderate, but the average loss at each fire was two or three times the loss expected in cities having ordinary fire protection. The water supply was satisfactory in many respects, although the pressure (the average being 52 pounds) was too low for automatic sprinkler equipments, standpipes, etc. The fire hydrants were of an old style, and many water mains were too small. There were four water services, varying for districts of different levels. It was stated that the fire department was satisfactory in most respects, but that the building laws were not enforced thoroughly and impartially. The fire-alarm system was criticised adversely.

The "congested-value district" was bounded on the north by a mixed mercantile, warehouse, and dwelling section; on the west by a fashionable boarding-house, apartment, and residence district; on the south by a compactly built mixed district composed of dwellings and manufacturing and mercantile buildings, and on the east by the Bay of San Francisco. This district consisted of 101 blocks, containing 2,086 separate buildings, of which 2.2 per cent were fireproof, 68.3 were joisted brick, and 29.5 were frame buildings. There was only one sprinkler equipment in the district, and it was practically obsolete. Premises were generally clean and well cared for.

The "potential hazard" in the produce and commission district bounded by Battery, Washington, Drumm, and Commercial streets

inspectors claimed to have fou

"conflagration breeders." In regard to the blocks north of Market street and between Powell and Taylor streets they reported: "This section contains more serious exposures and conflagration breeders than any other equal area in the city." They reported "frequent high winds," the absence of modern protective devices generally, the "probability feature" alarmingly severe, the elements of a "conflagration hazard" present to a marked degree, and the topography unfavorable. In fact, "San Francisco has violated all underwriting traditions and precedents by not burning up; that it has not done so is largely due to the vigilance of the fire department, which can not be relied upon indefinitely to stave off the inevitable."

This report was locally regarded as very severe, and in some respects—for instance, when referring to winds, redwood lumber, and hilly topography being unfavorable—as erroneous; but, unfortunately for San Francisco, the prophecy has come true.

**EXTRACT FROM A SAN FRANCISCO FIRE EXPERT'S REPORT TO THE
BRITISH FIRE-PREVENTION COMMITTEE.**

George J. Wellington, who was born and reared in San Francisco, and therefore can not be accused of prejudice against that city, in his report to the British fire-prevention committee of London in 1906, says, among other things:

A glance at the city from a point of eminence shortly after the temblor had subsided at once disclosed the fact that San Francisco was doomed. Columns of smoke ascending from fires at many different points made apparent a condition that no fire department in existence could cope with, on account of the impossibility of assembling sufficient apparatus at each fire to control it.



tion in this respect has led to the use of inferior materials and the evasion of building laws and the underwriters' recommendations. San Francisco possesses building laws in plenty, which require enforcement rather than alteration. A valuable addition to present ordinances would be one similar to that in force in some European countries, which penalizes owners for fires that escape from their buildings, affording protection to men disposed to build well.

EFFECT OF THE LAYOUT OF THE CITY AND THE CHARACTER OF THE BUILDINGS.

San Francisco, as already stated, is divided into three great districts. Market street, the great artery of the city, 120 feet wide, runs southwestward from the bay, and divides the city into two parts—first, a level district on the south, largely filled with wooden buildings, factories, foundries, lodging houses, and the like, but around the bay extremity of the street covered to a considerable extent with buildings of brick, stone, or steel frame; second, the uneven and in its remoter parts hilly district on the north. This northerly portion is subdivided by Van Ness avenue, which separates the older residence district from the newer one on the west.

In the older section of the city, between Market street and Van Ness avenue, the streets had been established under the old Spanish system of "100-vara lots," as they are locally known, each block containing about 76,000 square feet. West of Van Ness avenue and south of Market street, in parts of the city more recently surveyed and built upon, the blocks are much larger, and—particularly along Market, Mission, and adjacent streets to the south—were built up with very long rows of buildings, many of them continuous for hundreds of feet. These blocks were so large that it was found necessary, or at least convenient, to subdivide many of them by narrow streets or alleys that permitted the ingress and egress of carts and drays. It was easy for the flames to pass across these narrow streets, and the heat was in many places so great that buildings on the opposite side of the street were ignited by the heated air without the passage of any flames.

More than 90 per cent of the buildings in San Francisco were of wooden-frame construction, and many of the new, modern, and so-called "fireproof" buildings were surrounded by frame structures of an old type, and, of course, were injured or destroyed by their combustion. The fire limits permitted these wooden structures to approach rather close to the business section; and in the congested business district at least 30 per cent of the buildings were of frame construction, some of them four or five stories in height. Outside of the congested district many business houses and almost all dwellings were frame structures, and except in the outskirts of the city

were closely built in long rows extending over entire blocks. In the business district almost every separate structure was close to its neighbors. Wide, uncovered spaces separating buildings were, as a rule, confined to the outlying suburbs. In the compactly built district of wooden structures a house every three minutes was frequently the rate of destruction from the fire during the high wind that prevailed at times.

In the congested business district about 75 per cent of the streets were 60 feet wide, and a few (about 30 per cent) were at least 80 feet wide. These streets offered very little obstruction to the passage of the flames or heated air, and it was aided by the winds that were caused largely by the conflagration.

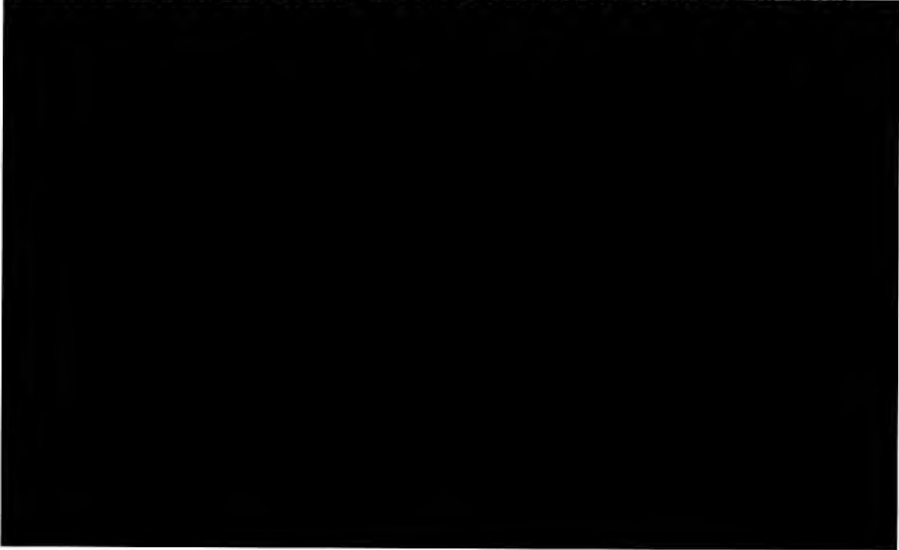
The height limit as established by the city ordinances was 220 feet for buildings of class A, 100 feet for class B, 82 feet for class C, and 45 feet for frame buildings. Brick buildings with wooden joists were therefore allowed to be built to a height of eight stories if furnished with wire-lath and plaster ceilings, thus affording the fire admirable opportunities for destruction.

BEHAVIOR OF STRUCTURAL STEEL AND STEEL-FRAME BUILDINGS SUBJECTED TO THE EARTHQUAKE AND FIRE.

EFFECTS DUE PRIMARILY TO THE EARTHQUAKE.

INTRODUCTION.

Structural steel as a building material and as a principal stress resistant in high steel-frame buildings has greatly increased in favor



FOUNDATIONS.

It is believed that every building whose foundations were well and strongly established—upon deep piling, as the Union Ferry Building and the Merchants' Exchange; with reenforced-concrete slab, as the Call Building; upon separate concrete piers or grillages resting upon good beds having a uniform load per square foot, as the Union Savings Bank in Oakland; or upon any other type of excellent foundation—escaped injury by the earthquake to the foundations themselves, nor did the superstructure owe any damage to inefficiency in those foundations.

The central portion of California was subjected to a severe earthquake in 1868, and has, on a number of occasions since, been slightly shaken by earthquake shocks, but many architects and engineers, and the people generally, had become so accustomed to these slight movements of the earth's crust that little attention was paid to them, and, so far as the writer can learn, architects had believed that in establishing solid foundations for high steel buildings, with good anchorage and bracing, adequate to take care of extreme wind force, they had sufficiently guarded against the effects of any earthquake vibrations which might occur. As a matter of fact, the provisions thus made seem to have been ample and safe so far as any disturbance of the foundations or any lack of support of the superstructure has been detected. Notwithstanding the severe vibrations these tall buildings have been called upon to endure, they have remained plumb and very slightly damaged by the earthquake.

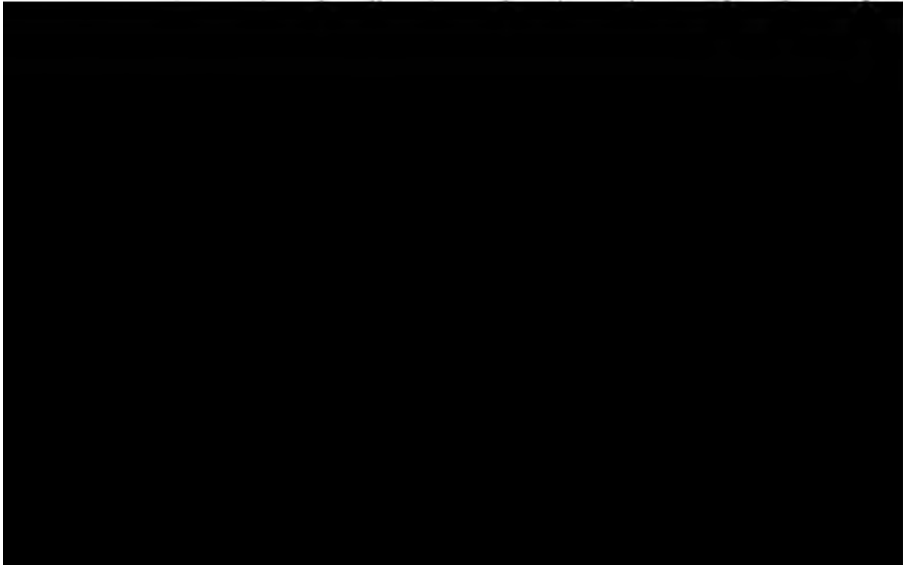
STRUCTURAL-STEEL FRAMES EXPOSED TO VIBRATORY MOTION.

As stated by A. O. Leuschner, secretary of the California earthquake commission, and also by Professor Omori, the distinguished seismologist of Japan, the vibratory motion in Berkeley and in San Francisco was approximately 3 inches in a horizontal direction and about 1 inch vertically, the time of the first oscillation being one second. This is understood to be the vibration on very hard soil or solid rock. Where the soil was softer and less coherent the waves became longer and the movement slower.

This vibratory motion had a tendency to move the foundation of a high building and the basement immediately in connection with it forward and back, and perhaps to move some of its columns in opposite directions, although this is not certain. At any rate, it apparently had the effect, owing to the inertia of the mass of the upper part of the building, of bringing a maximum bending moment to bear on the frame at some point between the basement and the top

of the building—to speak roughly, somewhere near the middle stories. It also seemed to have the effect of producing a horizontal shearing stress in the frame, particularly above and near the basement. The frames in these high buildings seemed to be the most severely wrenched, and the exterior walls, stairways, linings, etc., most injuriously cracked in these middle stories. For example, the magnificent eighteen-story Call Building seemed to be well braced against bending moment and shear, but the eyebars from the tenth to the sixteenth floor and the transverse wind bracing are reported to be somewhat buckled, the maximum occurring on the thirteenth floor. The braces were warped on all four sides of the building, and there was also probably some slight distortion of the steel frame from the tenth to the thirteenth floors. The exterior veneer of stone remained practically intact up to the tenth floor, above which, up to the sixteenth, there was an increasing amount of damage, some of the stone being considerably out of place. (See also p. 146.) The same thing practically can be said of the new Chronicle Building, the damage to the stonework of which can be noted by a close inspection of Pl. XXX, *B*. The earthquake proved the absolute necessity of bracing steel-frame buildings with diagonal braces, so far as the requirements of use will allow. The Mutual Savings Bank and the Shreve and Atlas high steel-frame buildings have such bracing and remained entirely plumb after the earthquake. The St. Francis Hotel and the Call Building were somewhat similarly braced and were also left in reasonably good condition.

Some architectural authorities assert that wind bracing put in liberally for an allowance of 30 pounds pressure per square foot will



MASONRY WALLS AND STONEMWORK.

The stone exteriors of all the high steel-frame buildings were to a greater or less extent cracked or injured under the action of the earthquake. In some places, owing probably to imperfect bond between the veneer and the steel frame, the stone veneer was displaced and the walls were bulged outward; in others, blocks were thrown to the ground and bricks or arch stones from windows and other exterior openings were dropped out of place. This disintegrating effect had its maximum in the intermediate stories between the top and the base of the building, a very good example being the Union Savings Bank in Oakland. This eleven-story steel-frame, stone-veneer structure gave opportunity for careful and comprehensive study of earthquake effects independently of fire, since it is really the only high steel-frame structure in the disturbed area which was not subjected to fire. In this building the steel frame is intact and uninjured, so far as can be ascertained. The marble veneer along the stairways and corridors and the sandstone exterior, particularly in the fourth, fifth, sixth, and seventh stories, were somewhat cracked and disturbed, indicating not only a bending but a shearing action; and the brick in the arches in some of the windows in these stories have dropped to the ground. Otherwise the building escaped damage, and it has been continuously in use since the earthquake.

The Aronson Building, at Third and Mission streets, had stone piers running from the bed up to the street level. These were badly wrenched and cracked by sheer action, and in the ninth story two courses of stone in the arches above the soffit course were badly cracked, apparently for the same reason. In the Call Building, where the stonework ends at the sidewalk level, the corner piers were not found to be cracked, but in the James Flood Building (Pls. XXXIII, *B*; XXXV, *A*), where the stonework extends to the bottom of the basement, the corner piers were cracked by earthquake action.

RELIABILITY OF STRUCTURAL STEEL.

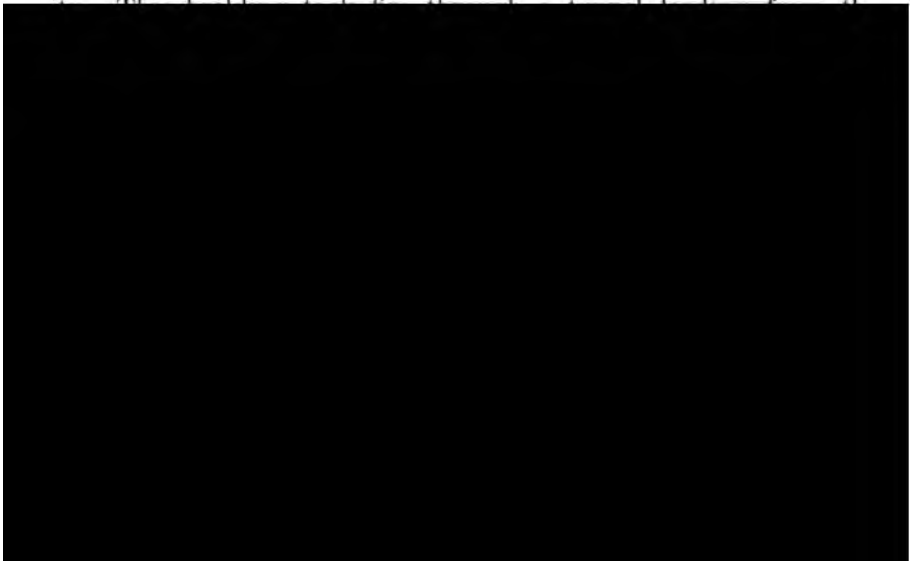
Structural steel is a very reliable material. It is produced and also placed in position by high-class skilled labor and is not subject to the flaws which sometimes appear in concrete work as a result of poor quality of labor and inefficient inspection. Builders in this country have had much experience in the use of structural steel, and feel sure of what it will do and for what it stands. It is no longer in the experimental stage as to resistance either to earthquake tremors or, when properly fireproofed, to conflagration. Constructors in San Francisco feel that this material has safely and triumphantly passed through a most trying ordeal.

EFFECTS OF THE FIRE.

BUILDINGS.

Structural steel in the steel-frame buildings subjected to the terrific heat of the great conflagration behaved satisfactorily wherever it was properly and amply protected by any method adopted for fireproofing. In no instance that has come under the observation of the writer has the steel been injured or deformed where such fireproofing was of the proper kind and remained intact after the earthquake. Unfortunately, in many places there was practically no fireproofing whatever, or it was very poor in design or workmanship, or both, and as a consequence failed miserably. Columns were softened and buckled. Girders were softened to such a degree that they sank by their own weight, some pulling after them the walls into which they were built, others falling into the fiery furnace below, as in the Cowell Building (Pl. LI, *B*), where the fireproofing either was lacking or proved defective in the fire. In such places the columns were buckled and some of them telescoped, thus removing all support for the floors above. In other buildings where the fireproofing was fairly good and effective, as in the James Flood and the Call buildings, the structure remained ready for rehabilitation. Although all the steel girders or columns that were subjected to intense heat on account of lack of fireproofing did not fall, yet many of them were rendered unfit for further use.

Prominent among the steel structures was the eighteen-story Call Building, with dome and lantern, the architectural pride of the



the fire, it is being rapidly refitted for store and office occupation. The Western Pacific Bank reoccupied its old quarters on the first floor of this building almost immediately after the fire.

FIREPROOFING.

GENERAL CONDITIONS.

It can be truthfully stated that perfect fireproofing of buildings in San Francisco, even in those of the newest and most modern type, was the exception and not the rule. The bent or broken columns and the distorted or disfigured steel girders in many of the burned buildings demonstrate this fact (Pl. XXVII, *B*). Wherever structural-steel framework was covered with fireproofing material of the best design, executed with conscientious, skillful workmanship, the steel remained uninjured after the fire.

The lessons taught by the great Chicago and Baltimore fires had been applied by but few of the architects of San Francisco, on account of cost restrictions insisted on by owners, and very much of the damage inflicted on these high-class structures during the conflagration is directly traceable to the imperfect fireproofing put in, or to the entire absence of fireproofing. Some of the failures were evidently and directly attributable to poor workmanship.

CONCRETE.

There are two opposing parties in the matter of fireproofing in San Francisco—those who have favored the hollow-tile system, and those who believe in concrete as the best fireproofing material. The Bekins Van and Storage Company's warehouse, the only building of considerable size in the city constructed of reinforced concrete, has already been mentioned as resisting the action of the earthquake and fire. In this building the concrete acted as a perfect fireproofing protection for the steel.

Good Portland-cement concrete has won a triumph for itself in fireproofing in San Francisco, for wherever well made and properly laid upon the steel girders or columns, it protected the metal. In very hot fires the exterior portions were disintegrated, and in some places the whole mass was cracked, necessitating removal, but the fireproofing it furnished during the conflagration was excellent. Examination showed also that it protected well against rust. The heat to which it was subjected was very great, in places common mortar being fused and ironwork in walls melted.

The steel beams and girders in the St. Francis Hotel, the Merchants' Exchange, the Mutual Savings Bank, and other similar structures that were thoroughly fireproofed with concrete endured the fire exceedingly well.

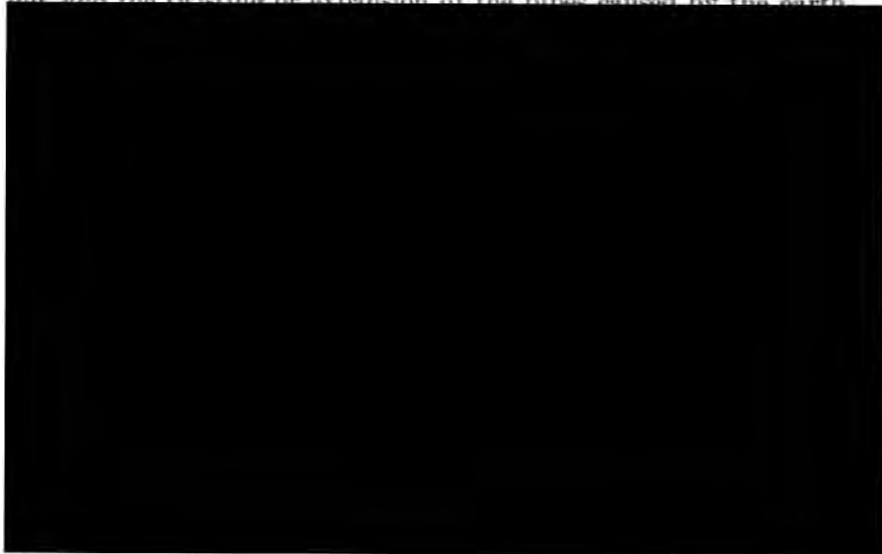
The weight of Portland-cement concrete is a drawback, and, moreover, concrete is expensive when well made and applied. Cinder concrete was well esteemed for fireproofing for floors, but the scarcity of good cinders in the city rendered its general employment impracticable.

TERRA COTTA.

As fireproofing for floors terra-cotta tiling has not given universal satisfaction. It is lighter than concrete, but the wrenching of buildings during the earthquake opened many of the joints and the mortar was destroyed—as in the Mills Building, a large ten-story steel-frame structure of the older type, having self-supporting walls. The mortar joints in the tiling were started by the earthquake, and the mortar was disintegrated by the fire, the floors being destroyed and the lower surfaces of the tiling badly spalled. The same effect was noticeable to a certain extent in the excellent Union Trust, Crocker, and James Flood buildings. In the last named the flooring was fireproofed with terra-cotta arched tiles, covered with concrete on top and finished beneath by an efficient ceiling plastered on wire lath. The fireproofing was less injured in this building than in almost any other.

Terra-cotta fireproofing of columns was in many buildings a failure, not so much on account of the nature of the material as because of its insufficiency in quantity and poor or imperfect method of application. Wooden studs were in many places put behind the terra cotta. These burned out quickly, leaving the material unsupported. Pipes and wires were run up between the column and the fireproof-

ing, and the twisting or expansion of the pipes caused by the earth-



mesh, etc., was used than with the double wrapping. But even the latter proved to be too weak and disintegrable to pass successfully through a severe earthquake or a fire and a strong stream of water from a fire hose. The plaster quickly cracks and falls away from the metal. No doubt these materials will be used in the future by owners demanding cheapness of construction, but they will satisfy the requirements only in cases of mild exposure. Good gravel concrete in place of the plaster, if of considerable thickness, has been found to give better results.

The failure of the plaster and metal method and some other methods of fireproofing in San Francisco is directly traceable to the commands of owners to their architects to cheapen as far as practicable the fireproofing and the construction generally, in order to receive greater interest on their investments. Much of this cheapening has been done in spite of the protests of the designer, and it is in an entirely wrong direction; for rates of insurance are largely reduced with improvements in fireproofing, and as the cost of the steel frame and its proper fireproofing seldom exceeds 27 per cent of the cost of the building, it seems wise to protect the other 73 per cent with adequate materials.

BRICKWORK.

In some buildings in San Francisco, brick laid in rich Portland-cement mortar has been found to be an excellent fireproof covering; but it is objectionable on account of the bulkiness of the brick and the rusting of the steel, as in basement stories. Good brick withstood the severe fire well, and where laid in rich cement afforded a strong fireproof wall or pier. At least 4 inches of brickwork was found necessary, and a layer of concrete 3 inches in thickness between that and the steel was a great improvement and served well to protect the steel from rust. But this method will probably not be followed in general, on account of weight, bulk, and expense. Hollow brick and tiling were efficient also when properly and liberally used, porous tiles proving to be the better.

The well-known Palace Hotel was built about thirty years ago, a few years after the earthquake of 1868, and before the introduction of steel-frame structures and concrete steel. It was intended to be earthquake proof as well as fireproof, and was built with very heavy walls of brick, most of them being 2 feet or more in thickness, laid in cement mortar, and strongly braced by many cross and partition walls. In the brickwork, at every 3 or 4 feet in height, were laid bands of iron, riveted together at their ends and crossings. This building, although of the old type, successfully endured the great earthquake, its walls being practically uninjured (Pl. XXX, B);

and although gutted by the fire, which gained access through the unprotected windows and wooden casings, was so strong on its foundations that very vigorous blasting operations were required to throw down its walls.

REENFORCED CONCRETE.

There was in San Francisco at the time of the earthquake only one building of considerable size constructed of reenforced concrete. This fact was due to the opposition of certain labor unions to the use of this material in place of brick and stone.

The building referred to is that of the Bekins Van and Storage Company, at 190 West Mission street (Pl. XXVII, 11). This building had outside walls of brick, but was massively constructed on the interior with columns, beams, and floors of reenforced concrete. It was originally intended to carry it to a height of four stories, but on account of the earthquake, which occurred during construction, the building was finished to include only the second story. At the time of the fire the permanent doors of iron were not in place, and the fire gained access to the front or south room, where very slight damage was inflicted. The entire main interior and the goods stored therein were unharmed, and the building has been in continuous use since completion. The brick building adjoining, however, was badly injured by the earthquake and was afterwards burned.

LESSONS FROM THE VARIOUS TYPES OF BUILDINGS.

Great destructive earthquakes have seldom occurred twice in the



worse, were of very poor quality. In contrast to such construction were the United States Government buildings—the mint and the appraisers' (or customs) building (Pl. XXVIII, A), in San Francisco, and the post-office building in Oakland—all of which were either entirely uninjured or very slightly injured by the earthquake. These buildings were well designed and constructed with the best materials and workmanship, upon foundations that had been tested and found strong and satisfactory. The results to both of these classes of buildings were fully to be expected.

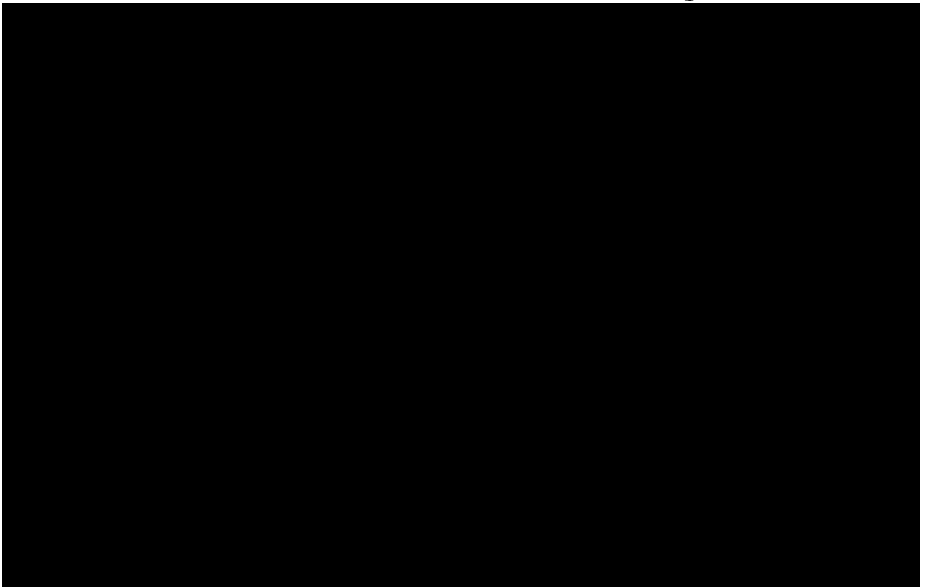
As a second class of buildings that suffered badly may be grouped those of the oldest type of wooden structure in San Francisco, lightly resting upon slim wooden underpinning, which stood upon soft and unstable soil or loose, unconsolidated sand. Such houses went down at the first shock, as one would naturally expect. In contrast to these flimsy structures are the thousands of more substantially constructed wooden buildings that still stand intact, except as to chimneys and some plastering, all over the unburned part of the city. These structures were built fairly well and upon stable foundations; and the writer believes from his personal observation that no well-founded and well-constructed building of wood in San Francisco was injured to a greater degree than those just mentioned. In a country subject to earthquakes a strongly framed and well-founded wooden house, not exceeding three stories in height, with nondisintegrating plaster and finish, light tile chimneys, and ample fire prevention and protection, would seem to be the ideal type of residence structure.

Experience shows that buildings constructed with exterior brick walls laid in common mortar, with timber columns and girders, tied and braced little or not at all, constitute a third class of buildings which are nonresistant to a severe earthquake, particularly if they are erected upon a poor foundation. Even if the girders and columns are of metal, they are pulled apart, and the walls fall inward or outward during the shock. Only rich Portland cement, laid with wetted brick, and strong joists, ties, and anchorage, endured the stress.

The behavior of the high steel-frame office buildings, which constitute the fourth class, has shown that in order to resist perfectly the bending moments and shears induced by the swaying due to the earthquake movement, such buildings should be stiffened in their joints and connections by the best riveting combinations, and knee and other bracing, particularly at or near the ground floor. This requirement is of the utmost importance, and so also is the one that the swaying referred to should be diminished by the liberal introduction of **diagonal and wind bracing throughout**. The proper bracing in the ~~lower stories has in some buildings been omitted, on the demand of~~

owner or lessee, to afford more glass or light space, but such design has a weakening effect, and should be discouraged. The Marston Building, on Kearney street, is an object lesson in this respect. On the other hand, the Whittell Building, on Geary street, near Union square, is commended for its deep plate girders and heavy steel generally. It stood well, and no rivets were sheared. Columns, exterior and interior, in steel-frame buildings, should in future be put in more liberally on the first and second stories, and the strongest joints and connections should be adopted in order to resist the bending and shearing. These improvements will greatly stiffen the steel frame, and prevent the cracking of the walls. The Kohl Building, thus stiffened by lattice girders on all floors, was uninjured in its exterior stonework and brickwork, although built upon the edge of the made ground along the old shore line. With such strengthening the high steel structures will safely endure an earthquake of even greater severity than that of April 18, 1906. This kind of building has proved its worth and reliability, and minor improvements, as advocated, will produce an enduring structure.

In a fifth class are to be placed, but not as failures, concrete and reenforced-concrete structures. These have become popular with a large number of designers in San Francisco, on account of the strength claimed for them, and on account of the indestructibility, facility of construction, and fire and rust protection that their materials afford. Unfortunately for San Francisco, there were very few structures of concrete or reenforced concrete in the city at the time of her great trial; but these few behaved well during both the earth-



tied and anchored together. San Francisco's experience has proved that this rule is a most important one to follow in all brick and stone construction, and its neglect in the past has resulted in much loss and ruin.

FIRE-FIGHTING APPARATUS AND FIRE-RESISTING MATERIALS.

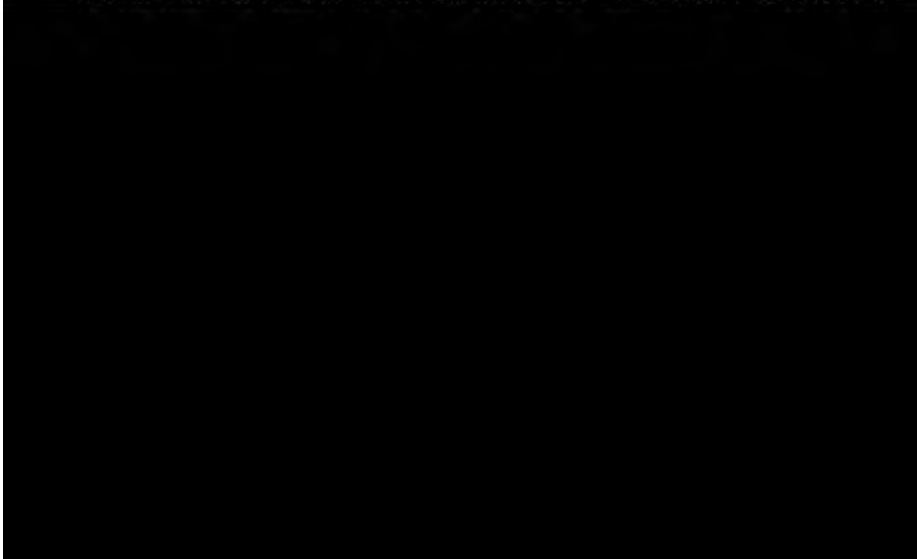
The damage inflicted on San Francisco from the direct and immediate effects of the earthquake was relatively small, being estimated at only 3 to 10 per cent of the total loss; but a subsequent and indirect effect was to paralyze the water supply and its distributing system, start a great conflagration and render impossible its extinguishment with the means at hand, cause the death of at least 600 human beings, burn approximately \$500,000,000 worth of property, render homeless and miserable 200,000 people, and inflict remoter damages to business, commerce, and labor, only to be estimated in the future. Inasmuch as it can be plainly seen, by looking backward, that nearly all of this destruction and suffering might have been prevented by wise foresight and provision, it is felt that a warning should be sent to all the cities in the world. Any city that disregards this warning will be guilty of a great crime.

San Francisco should have had separate and ample water mains entering the city on several independent lines from different sources of supply, and numerous distributing reservoirs on the hills in various parts of the city, always well filled, independent and yet with a distributing system meshing the entire area, with its pipes so joined or valved that they could be separated or united as desired. There should have been in that city, almost surrounded by salt water, a separate system of flexible salt-water mains for fire and sewer purposes, and numerous large cisterns in her streets, laid in reenforced concrete, with somewhat flexible lining and pipes. These cisterns, only a few blocks apart, should have been filled at all times with salt water. There should have been many wide streets—like Van Ness avenue, where the fire was finally checked—and many large squares, the city being thus divided into numerous fire districts. The fire department should have included a dynamiting corps of experienced fire fighters, and a number of fire boats always ready along the water front and among the shipping. None of these things did San Francisco have. With these means available, probably this story of the greatest fire in history would never have been written.

Of a building's entire fire risk, that from fire within the building is estimated, on the average, at 40 per cent, the other 60 per cent of the risk being from exterior fires. This risk for interior fires should

be reduced to a minimum by ample provision for fire prevention. As far as practicable, combustible material should be eliminated. Several of the fine so-called fireproof buildings in San Francisco were injured chiefly by the burning of their wooden trim, floors, doors, office furniture, papers, books, carpets, rugs, etc. Wooden floors have proved to be dangerous and objectionable; but in some places non-combustible wood may be used for them and for the interior trim, as, for example, where the heat could never be very great. Metal trim, doors, windows, sash, and casings, together with plate glass, or, better, wire glass, may confine a fire to a single room, preventing a general combustion. Adequate fire-extinguishing apparatus—such as fire hose, always connected with good water pressure, wells with automatic pumps, and tanks in the basement or upon the roof, with pipe connections—was lacking in nearly all of San Francisco's buildings, even in those of the highest class. In the California Electric Company's building the standpipes, with attached hose, the well, pump, and tank in the basement, and the roof tank, together with the metal sash and the wire-glass windows, proved the value of such a private system, saving that property from the hot fire around it, though every adjacent structure was burned. As this building was not fireproof, the value of the fire-extinguishing system can be well understood, and had all the large establishments been equally well equipped the conflagration would have been quickly checked and a vast amount of property saved. Automatic sprinklers connected with the above-mentioned plant will afford excellent fire protection within and will greatly reduce insurance rates.

While the fire danger from exterior fires to a given building is



scanty private supply of water, made a desperate and gallant fight from the roof of the building and within, and saved it, little injured.

As most metallic shutters rapidly deteriorate with time, rust, and weather, and often become jammed so that they will not close, many architects prefer wire glass in hollow metallic sash and window sprinklers. This combination has proved effective.

San Francisco's experience indicates that wells and elevator shafts, running up through many stories, should be guarded by brick or reenforced-concrete walls, fitted with double metal rolling doors, bolted to the walls to allow for expansion, or with automatic sliding doors and wire-glass partitions. There was little or no provision for cutting off the draft of air that will ascend through such a shaft during a fire, and great destruction resulted in consequence. The Call Building took fire from the power house behind it, on the other side of Stevenson street, the heat being drawn through the tunnel to the elevator shaft, up which it rushed with the fierce draft given by the 18 stories, breaking glass and burning doors, furniture, trimmings, and office contents. The Telephone Building, on Bush street (Pl. XLI, A), met a similar fate, being consumed from within. This new structure was claimed to have the best fire protection in the city.

The importance and value of real protection will be appreciated when it is stated that a third-class building with a complete fire-prevention plant is insured for less than a first-class one that does not have it. This fact should be understood by all owners. Moreover, all parts of an establishment should be equally protected, for the fire may begin anywhere. The new Telephone Building was burned owing to the nonobservance of this rule, catching fire through the unprotected wooden back door of the basement. The structure was fitted with "tin-clad shutters" and wire glass on the side and rear openings and with steel rolling shutters in front. The fire broke through the rear wooden door into two well shafts and a corridor and, rushing upward, consumed every floor. The building was destroyed by a fire that entered through a single unprotected opening. The tin-clad shutters were destroyed and much of the wire glass was melted or broken by the hot fire. The rolling shutters in front still hung, but were bent so that the windows were exposed.

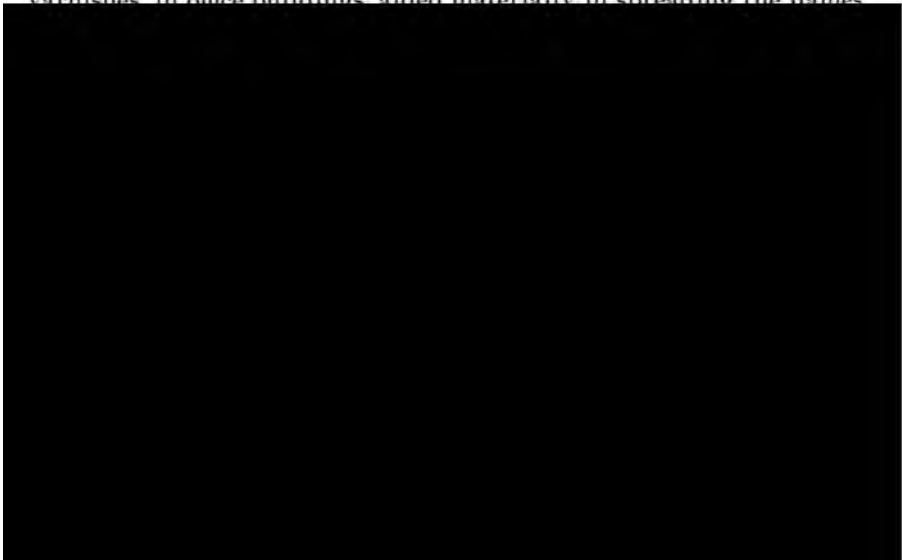
Concrete floors with metallic-mesh reenforcement are strongly recommended for strength and fireproof character. Noncombustible wooden floors, doors, and trim were installed in a few buildings, and under ordinary conditions would probably have limited the destruction to "one-room fires," but the heat was so high, and in general the bulk of papers, books, and furniture so great, that all were consumed. A noninflammable substitute for woodwork and trim generally is greatly to be desired.

Double windows of wire glass in hollow metallic frames are recommended, or where such material would be objectionable by cutting off the view, double plate glass is considered next best. Interior doors should be of metal, or at any rate metal covered, in fireproof buildings, and the light for corridors and halls should come through wire glass. As the installation of wire glass, metallic rolling shutters, and metal sash involves only a small percentage of the cost of the building, and as these materials have proved to be of such excellent service as fire protection when of the best quality and workmanship, a wise economy demands their use in every important fireproof building.

Capitalists and owners must understand that perfect fire protection for structural steel is necessarily expensive. Any so-called fireproofing that is cheap and flimsy is a delusion and will not serve. The application of an effective method insures permanence of the structure and at the same time greatly reduces the rates of insurance. Steel columns may be well fireproofed by surrounding them with the best quality of stone or cinder concrete 4 inches in thickness, or by 3 inches of either when hollow tiling is put on the exterior.

A 3-inch porous terra-cotta tiling, wrapped on the outside with wire, and with metal mesh used around the bed course of the column, has proved efficient. The mortar of the tiles should contain a large proportion of cement, and the tiles should be strongly anchored to the columns to prevent their falling away in earthquake or fire and so leaving the steel exposed.

In the great fire, decorations, trim, inflammable oil paints and varnishes, in office buildings, aided materially in spreading the flames



or even ruined by the earthquake, owing to imperfect anchorage and failure to cohere at their joints (PL XVII, A).

Granite, sandstone, and marble were badly cracked and spalled by the fire, much of the marble crumbling to powder. The granite piers in the front of the Hobart Building were nearly all chipped away, and they are now reenforced by new temporary supports.

Chemical fire extinguishers were effectively used immediately after the earthquake in some of the uptown residences, thereby preventing an increase in the number of fire centers at the beginning of the conflagration. It is possible that numerous chemical engines and locally installed chemical extinguishing plants in the downtown districts might have greatly limited the spread of the flames, despite the dearth of water.

FINAL CONCLUSIONS.

EARTHQUAKE PROTECTION.

A proper foundation, stable and firm, is of vital importance, and particularly on soft, marshy, or made ground (Pls. XLIII, B; XLIV, A). Anchoring, bonding, and tying should be practiced with exactness in all masonry. Steel framing should be made heavier rather than lighter, and joints, connections, bracing, and flooring should be strongly united. Girders and columns should be made very stiff and, where practicable, continuous.

FIRE PROTECTION.

The lessons taught by the great fires of Boston, Chicago, and Baltimore have been verified by San Francisco's experience.

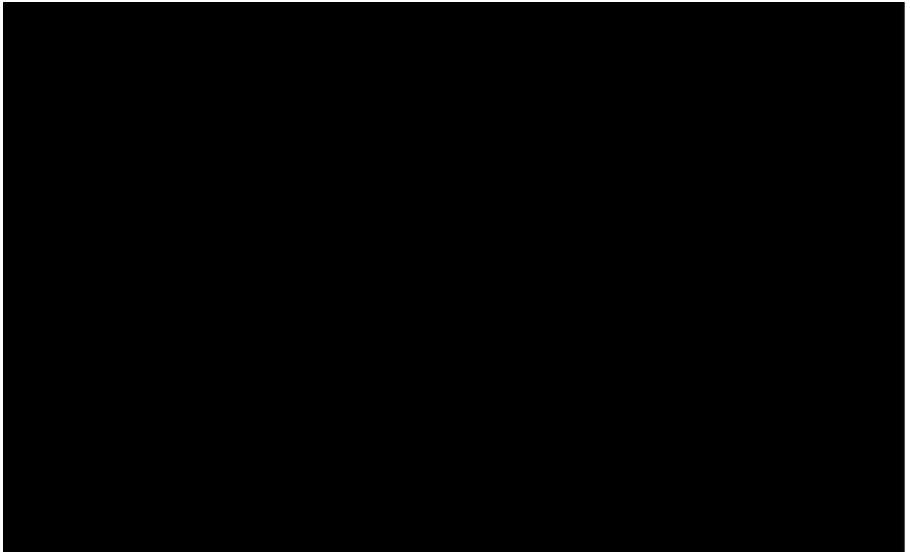
Fireproofing should be of the most perfect type, and no reasonable expense should be spared in its installation.

Roofs, roof appurtenances, and skylights should be given ample protection against fires from without. A great excess of fire hose and apparatus, beyond ordinary needs, should be available. A strong bond for fireproof tiling, etc., for both girder and column protection, is essential. Protection for front windows, as well as for side and rear ones, is of vital importance. Good protection for steel frames and steel roof trusses in attics or other exposed or unusual places should be provided. Liberal use should be made of fire retardant in windows, doors, transoms, etc. Wise and liberal use of concrete and reenforced concrete for girder and column fireproofing has proved its saving quality. Interior fire protection and prevention by wells, pumps, sprinklers, and water tanks vastly lessen fire risk.

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LIST OF PAPERS RELATING TO THE EARTHQUAKE AND FIRE.

AMERICAN SOCIETY OF CIVIL ENGINEERS. Report of a general committee and of six special committees of the San Francisco association of members of the American Society of Civil Engineers. The effects of the San Francisco earthquake of April 18, 1906, on engineering constructions: *Am. Soc. Civil Eng., Proc.*, vol. 33, no. 3, pp. 299-354, 31 pls., 3 figs., March, 1907. Discussion by Edwin Duryea and others: *Idem*, vol. 33, no. 5, pp. 537-547, 1 pl., May, 1907.

BAUER, L. A. Magnetograph records of earthquakes, with special reference to the San Francisco earthquake, April 18, 1906: *Terrestrial Magnetism and Atmospheric Electricity*, vol. 11, no. 3, pp. 135-144, 2 figs., September, 1906.

— and BURBANK, J. E. The San Francisco earthquake of April 18, 1906, as recorded by the Coast and Geodetic Survey magnetic observatories: *Nat. Geog. Mag.*, vol. 17, no. 5, pp. 298-300, May, 1906.

BRANNER, JOHN C. The California earthquake; movements along the Santa Cruz fault line: *Eng. News*, vol. 55, no. 20, p. 542, May 17, 1906; *Palo Alto*, May 1, 1906.

CAREY, EVERETT P. The great fault of California and the San Francisco earthquake, April 18, 1906: *Jour. Geog.*, vol. 5, no. 7, pp. 289-301, 6 figs., 1906.

Discusses the faulting which produced the San Francisco earthquake and displacements along the line of fracture.

CHRISTY, S. B. Some lessons from the [San Francisco] earthquake: *Mg. and Sci. Press*, vol. 92, no. 17, pp. 273-274, April 28, 1906.

COOPER, A. S. The [San Francisco] earthquake explained: *Mg. and Sci. Press*, vol. 92, no. 24, pp. 401-402, June 16, 1906.

DAVIDSON, GEORGE. Points of interest involved in the San Francisco earthquake: *Am. Phil. Soc., Proc.*, vol. 45, pp. 178-182, 1906.

DAVISON, C. The San Francisco earthquake of April 18: *Sci. Am. Supp.*, vol. 61, no. 1586, pp. 25416-25417, May 26, 1906.

DERLETH, CHARLES, JR. Report [on the San Francisco earthquake]: *Eng. News*, vol. 55, no. 18, pp. 503-504, May 3, 1906; no. 19, pp. 525-526, May 10, 1906.

— Some effects of the San Francisco earthquake on waterworks, street sewers, car tracks, and buildings: *Eng. News*, vol. 55, no. 20, pp. 548-554, 20 figs., May 17, 1906.

— The destructive extent of the San Francisco earthquake of 1906: *Eng. News*, vol. 55, no. 26, pp. 707-713, 17 figs., June 28, 1906.

ENGINEERING NEWS. The San Francisco disaster: earthquake and fire ruin in the bay counties of California: *Eng. News*, vol. 55, no. 17, pp. 478-480, 1 fig., April 26, 1906.

FULLER, M. L. Comparative intensities of the New Madrid, Charleston, and San Francisco earthquakes (abstract): *Science*, new ser., vol. 23, pp. 917-918, June 15, 1906.

GALLOWAY, J. D. The recent earthquake in central California and the resulting fire in San Francisco: *Eng. News*, vol. 55, no. 19, pp. 523-525, 13 figs., May 10, 1906.

GILBERT, G. K. The cause and nature of earthquakes: *Mg. and Sci. Press*, vol. 92, no. 17, pp. 272-273, April 28, 1906.

HEILPRIN, ANGELO. The concurrence and interrelation of volcanic and seismic phenomena: *Science*, new ser., vol. 24, pp. 545-551, Nov. 2, 1906.

INGALLS, A. O. Earthquakes and their probable origin: *Northwest Mining Jour.*, July, pp. 2-12, 14 figs., 1906.

Presents a detailed discussion of the Pacific coast earthquakes from 1888 to 1898.

LAWSON, ANDREW C., and others. Preliminary report of the [California] State earthquake investigation commission: *Mg. and Sci. Press*, vol. 92, no. 24, pp. 390-401, 4 figs., June 16, 1906; *Sci. Am. Suppl.*, vol. 61, no. 1590, pp. 25482-25484, June 23, 1906; *Science*, new ser., vol. 23, pp. 961-967, June 29, 1906.

Includes various data relating to the geologic structure of the State of California and to the earthquake of April 18, 1906.

LEUSCHNER, A. O. The [San Francisco] earthquake: *Mg. and Sci. Press*, vol. 92, no. 17, p. 274, April 28, 1906.

MARVIN, C. F. The record of the great [San Francisco] earthquake written in Washington by the seismograph of the U. S. Weather Bureau: *Nat. Geog. Mag.*, vol. 17, no. 5, pp. 296-298, May, 1906.

MILNE, J. Seismological investigations. Eleventh report of the committee: *Brit. Assoc. Adv. Sci.*, Rept., 1906, pp. 92-103, 1907.

Contains references to North American earthquakes.

MOORE, C. F. Earthquake effects at Santa Clara, Palo Alto, and San Jose



cisco earthquake of April 18, 1906: Imperial Earthquake Investigation Committee, Tokyo, Japan, Bull., vol. 1, no. 1, pp. 26-43, 6 pls., January, 1907.

Tabulates seismographic records of the San Francisco earthquake made at various earthquake-observation stations and discusses the rate of transmission.

—— Comparison of the faults in the three earthquakes of Mino-Owari, Formosa, and San Francisco: Imperial Earthquake Investigation Committee, Bull., vol. 1, no. 2, pp. 70-73, 3 figs., 1907.

RANSOME, FREDERICK·LESLIE. The probable cause of the San Francisco earthquake: Nat. Geog. Mag., vol. 17, no. 5, pp. 280-296, 11 figs., May, 1906; Mg. and Sci. Press, vol. 92, no. 24, pp. 396-397, 1906.

Describes the geologic structure of the region surrounding San Francisco, Cal.

REDWAY, JACQUES W. Some notes on the San Francisco earthquake: Geog. Jour., vol. 29, pp. 436-440, 6 figs., 1907.

REID, HARRY FIELDING. Records of seismographs in North America and the Hawaiian Islands. No. 111: Terrestrial Magnetism and Atmospheric Electricity, vol. 11, no. 4, pp. 185-197, December, 1906.

[RICKARD, T. A.] The [San Francisco] earthquake: Mg. and Sci. Press, vol. 92, no. 17, pp. 270-272, April 28, 1906.

—— After the [San Francisco earthquake] disaster: Mg. and Sci. Press, vol. 92, no. 18, pp. 287-288, May 5, 1906.

—— Former earthquakes and their discarded lessons: Mg. and Sci. Press, vol. 92, no. 18, pp. 280-290, May 5, 1906.

—— and others. After earthquake and fire. A reprint of the articles and editorial comment appearing in the Mining and Scientific Press immediately after the disaster at San Francisco, April 18, 1906. San Francisco, Mining and Scientific Press, 1906. 194 pp., illus.

A reprint of papers appearing in the Mining and Scientific Press in the issues of April 28, May 5, and June 16, in the main relating to the San Francisco earthquake.

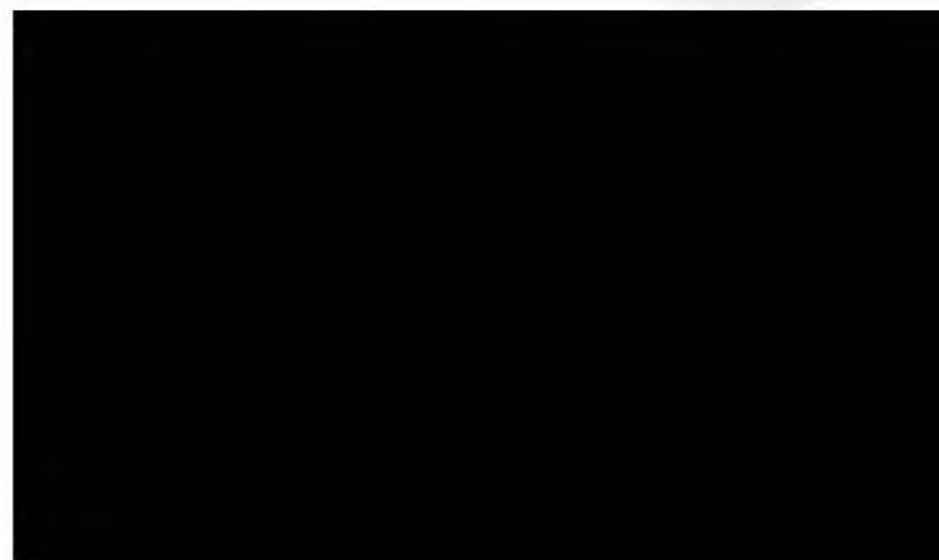
SEE, T. J. J. The cause of earthquakes, mountain formation, and kindred phenomena connected with the physics of the earth: Am. Phil. Soc., Proc., vol. 45, pp. 274-414, 17 figs., 1906.

STORMS, W. H. Earthquake lines: Mg. and Sci. Press, vol. 92, no. 18, p. 289, May 5, 1906.

TAPER, STEPHEN. Some local effects of the San Francisco earthquake: Jour. Geol., vol. 14, no. 4, pp. 303-315, 9 figs., 1906.

Describes the faulting which caused the earthquake and its movements as shown by various local displacements.

WEATHERBE, D'ARCY. First observations of the [San Francisco earthquake] catastrophe: Mg. and Sci. Press, vol. 92, no. 17, pp. 275-276, April 28, 1906.



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CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 324.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports; Q, Fuels; R, Structural materials. This paper is the first in Series R and bears the following title (B=Bulletin):

SERIES R, STRUCTURAL MATERIALS.

- B 324. The San Francisco earthquake and fire of April 18, 1906, and their effects on structures and structural materials; reports by G. K. Gilbert, R. I. Humphrey, J. S. Sewell, and Frank Soulé, with preface by J. A. Holmes. 1907. 170 pp., 57 pls.

Correspondence should be addressed to

THE DIRECTOR,

UNITED STATES GEOLOGICAL SURVEY,

WASHINGTON, D. C.

AUGUST, 1907.

1





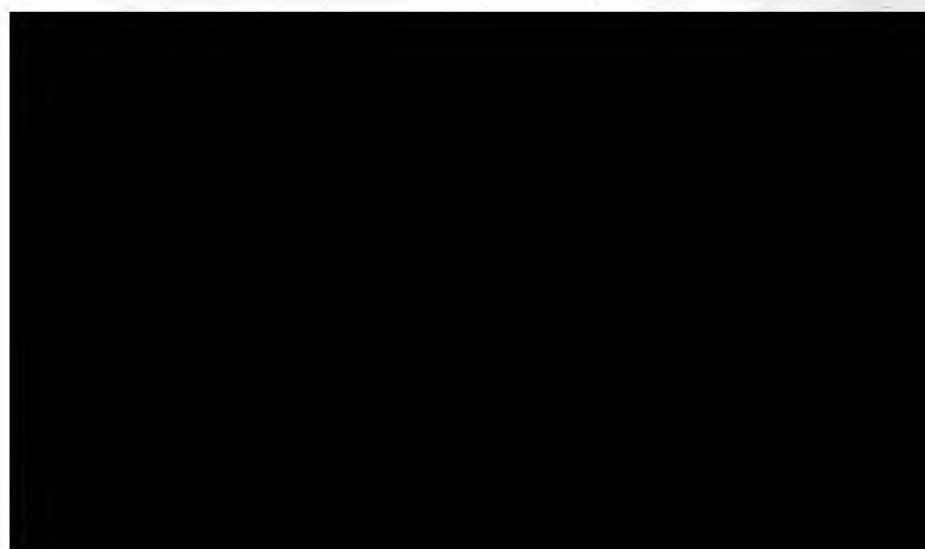
1. ROAD CROSSING FAULT TRACE NEAR POINT REYES STATION.
Looking southwest. Offset, 20 feet. Photograph by G. K. Gilbert.



2. FENCE PARTED BY EARTHQUAKE FAULT.

The fault trace or fracture accompanying the earthquake is conspicuous in the gap; the horizontal displacement is considerable. Photograph by G. K. Gilbert.

EARTHQUAKE EFFECTS ALONG THE FAULT TRACE.





REDWOOD TREE 6 FEET IN DIAMETER ON LINE OF FAULT SOUTH OF FORT ROSS

The tree was split to a height of 55 feet, with each half leaning in opposite directions. The opening is wedge-shaped at the base, running from a width of 6 inches at the base to a width of 1 foot at the top. The photograph is by Richard L. Humphrey.





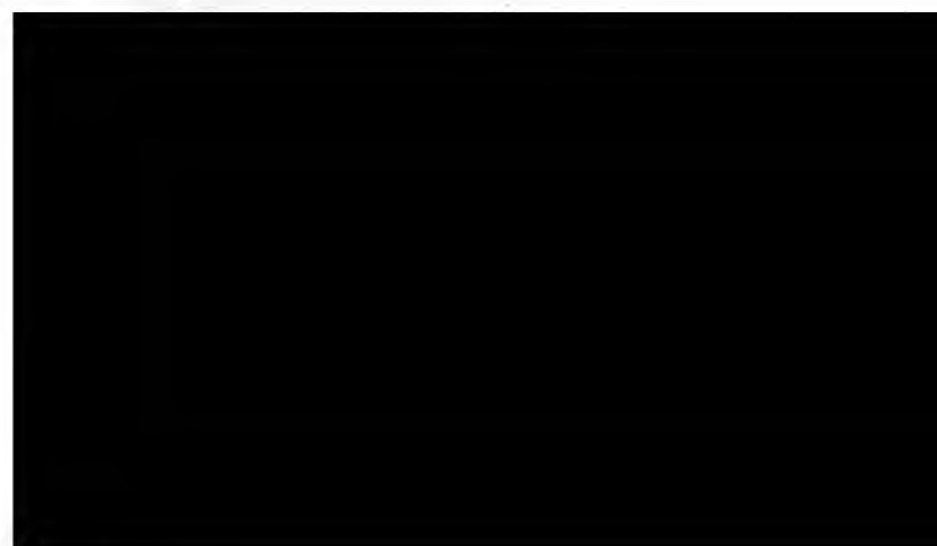
A



B

THE FAULT TRACE NEAR POINT REYES STATION.

A, Looking northwest; B, Looking southeast. Photographs by G. K. Gilbert.





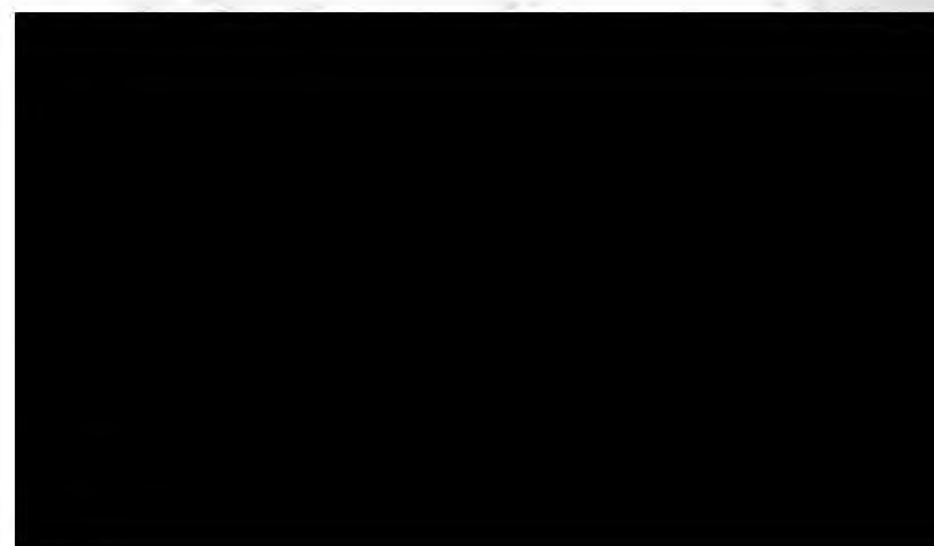
A. SECONDARY CRACKS, SHORE OF BOLINAS LAGOON.

Photograph by G. K. Gilbert.



B. SECONDARY CRACKS, WITH SETTLING, BOLINAS.

Photograph by G. K. Gilbert.





RESULTS OF SURVEY OF WINDY HARBOR, NANTUCKET, MASS.
JANUARY 1914





1. SETTLING 5 FEET ON DORE STREET BETWEEN BRYANT AND BRANNAN STREETS,
SAN FRANCISCO

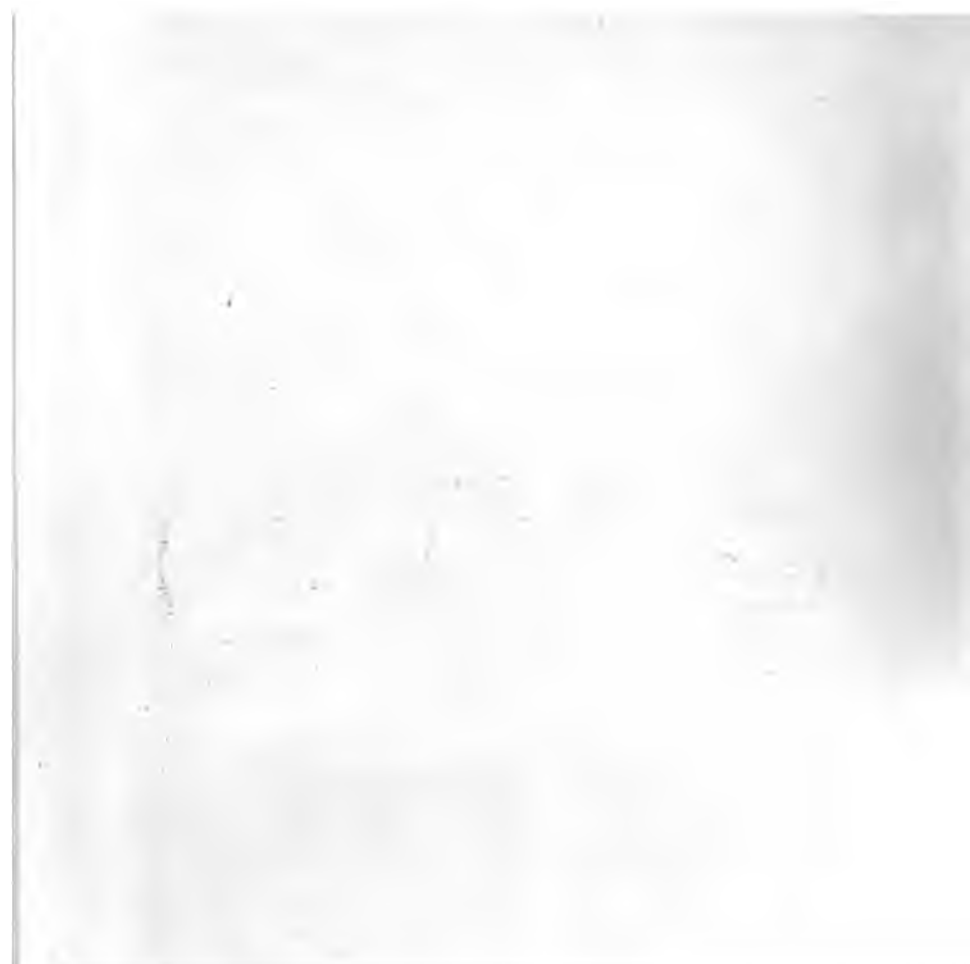
Photograph by Richard L. Humphrey.



2. BUCKLING CAUSED BY EARTH FLOW, HOWARD STREET, SAN FRANCISCO.

Photograph by G. K. Gilbert.

EARTHQUAKE EFFECTS ON MADE GROUND.





A



B

SHIFTED BOTTOM OF TOMALES BAY.

A. General view; B. Edge of new shoal. Photographs by G. K. Gilbert.

1

2





I. EARTHQUAKE RIDGES ON TIDAL FLAT, TOMALES BAY.

Photograph by G. K. Gilbert.



II. SLIPPING OF ALLUVIAL SOIL TOWARD SALINAS RIVER.

Grain field adjoining road along river between Spreckels's sugar mill and Salinas. Photograph by A. C. Lawson.





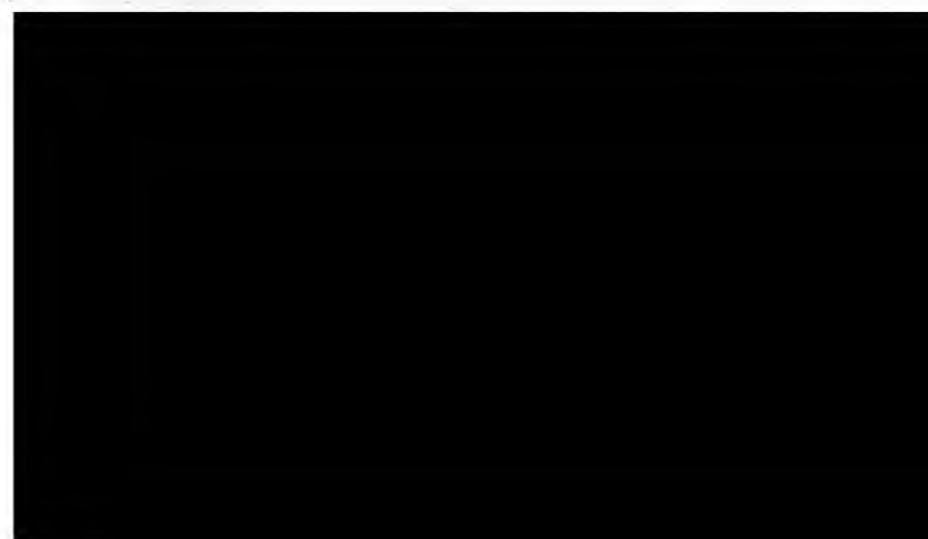
A



B

DAMAGE TO PILARCITOS 30-INCH PIPE LINE BY EARTHQUAKE.

A, Offset; *B*, Telescoping. Photographs submitted by Frank Soule.



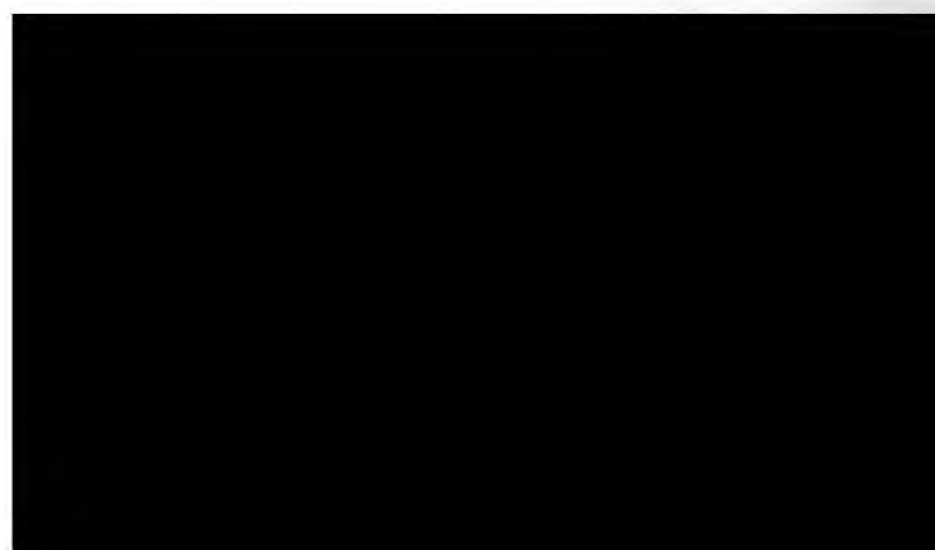


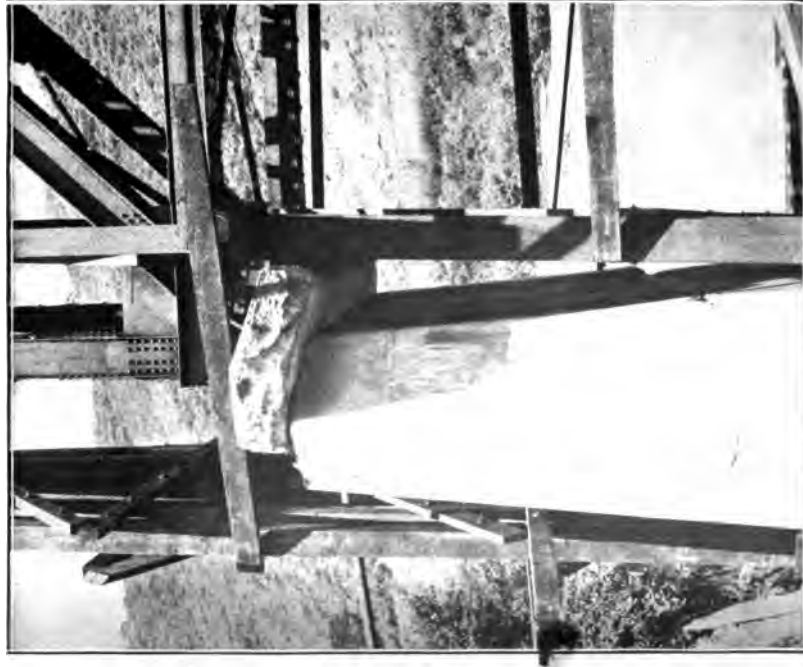
1. COLLAPSED PILARCITOS 30-INCH WROUGHT-IRON PIPE LINE, NEAR
TRESTLE CROSSING THE FAULT.

The slip produced a compression on the pipe line which buckled it, thereby throwing down the trestle support. The consequent parting of the pipe line suddenly released the water from the pipe, causing a vacuum which brought about the collapse. Photograph by Richard L. Humphrey.



2. HOUSE ON LINE OF FAULT, TORN ASUNDER BY EARTHQUAKE.
Near Wrights Station, on Southern Pacific Railroad. Photograph by Richard L. Humphrey.





4. RACKING AND SPALLING OF CONCRETE PIER DUE TO EARTHQUAKE.
Near south abutment of Southern Pacific Railroad bridge over Pajaro River. Photograph
by Richard L. Humphrey.



5. ENDURANCE OF CONCRETE DAM NEAR FAULT TRACE, AT CRYSTAL
SPRINGS LAKE, SAN MATEO.
Photograph by Richard L. Humphrey.





A. EFFECT OF EARTHQUAKE ON THE END AND THE INSUFFICIENTLY BRACED CENTRAL PORTION OF A BRICK BUILDING, SPRECKELS'S SUGAR MILL, ABOUT 4 MILES SOUTH OF SALINAS.

Note the stripping of brick pilasters from steel columns. Photograph by Richard L. Humphrey.



B. EARTHQUAKE WRECK OF NEW HALL OF JUSTICE, SAN JOSE, BUILT ON ALLUVIAL SOIL. Wreck due to poor quality of stonework and unnecessary massive construction. Photograph by Frank Soule.



I. COMPARATIVE EARTHQUAKE ENDURANCE OF DISSIMILAR STRUCTURES, AGNEW INSANE ASYLUM, NEAR SAN JOSE.

Tanks on steel trestle, undamaged, and circular brick stack, collapsed. Photograph by Richard L. Humphrey.



II. EARTHQUAKE EFFECT, HIGH SCHOOL BUILDING, SAN JOSE.

Photograph submitted by Frank Soule.





1. COMPARATIVE BEHAVIOR OF REENFORCED CONCRETE AND BRICKWORK UNDER EARTHQUAKE VIBRATION, MUSEUM, LELAND STANFORD JUNIOR UNIVERSITY.

The central portion, of reenforced concrete, was undamaged, but the brick wings collapsed. Photograph by Richard L. Humphrey.



2. COMPLETE WRECK BY EARTHQUAKE, COURT-HOUSE AND HALL OF RECORDS, SANTA ROSA.

Wreck due to light wooden framing, insufficient bracing, and poor mortar. Photograph submitted by Richard L. Humphrey.





.1. UNDAMAGED STEEL FRAMEWORK SUPPORTING DOME OF LIBRARY.



.2. COLLAPSE OF MASONRY WALLS AND STEEL FRAMEWORK OF LIBRARY, LELAND STANFORD JUNIOR UNIVERSITY.

ENDURANCE OF STEEL FRAMEWORK AS AFFECTED BY METHOD OF SUPPORT, LELAND STANFORD JUNIOR UNIVERSITY.

Photographs by Richard L. Murphy.





A



B

MEMORIAL ARCH, LELAND STANFORD JUNIOR UNIVERSITY.

A, Before the earthquake (photograph submitted by Richard L. Humphrey); *B*, Earthquake effect (photograph by Richard L. Humphrey). The beams designed to stiffen the walls were not tied to them and helped to batter them down when the shock came.

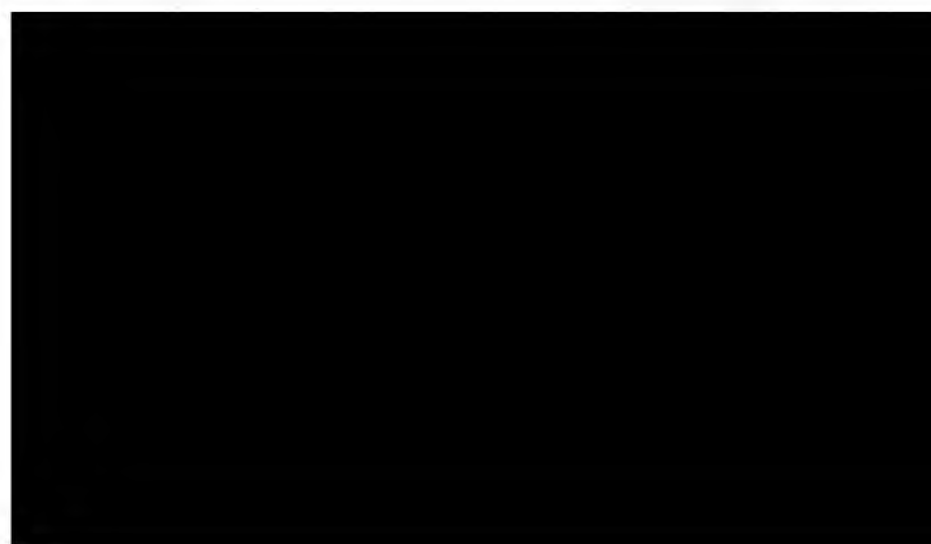




**I. COLLAPSE DUE TO LACK OF TIE BETWEEN WALLS AND FRAME. THIELE BUILDING
CEMENT BLOCK, PALO ALTO.
Photograph by Richard L. Humphrey.**



**J. COLLAPSED TOWER AND GENERAL EARTHQUAKE WRECKAGE, MEMORIAL CHURCH,
LELAND STANFORD JUNIOR UNIVERSITY.
Photograph by Richard L. Humphrey.**





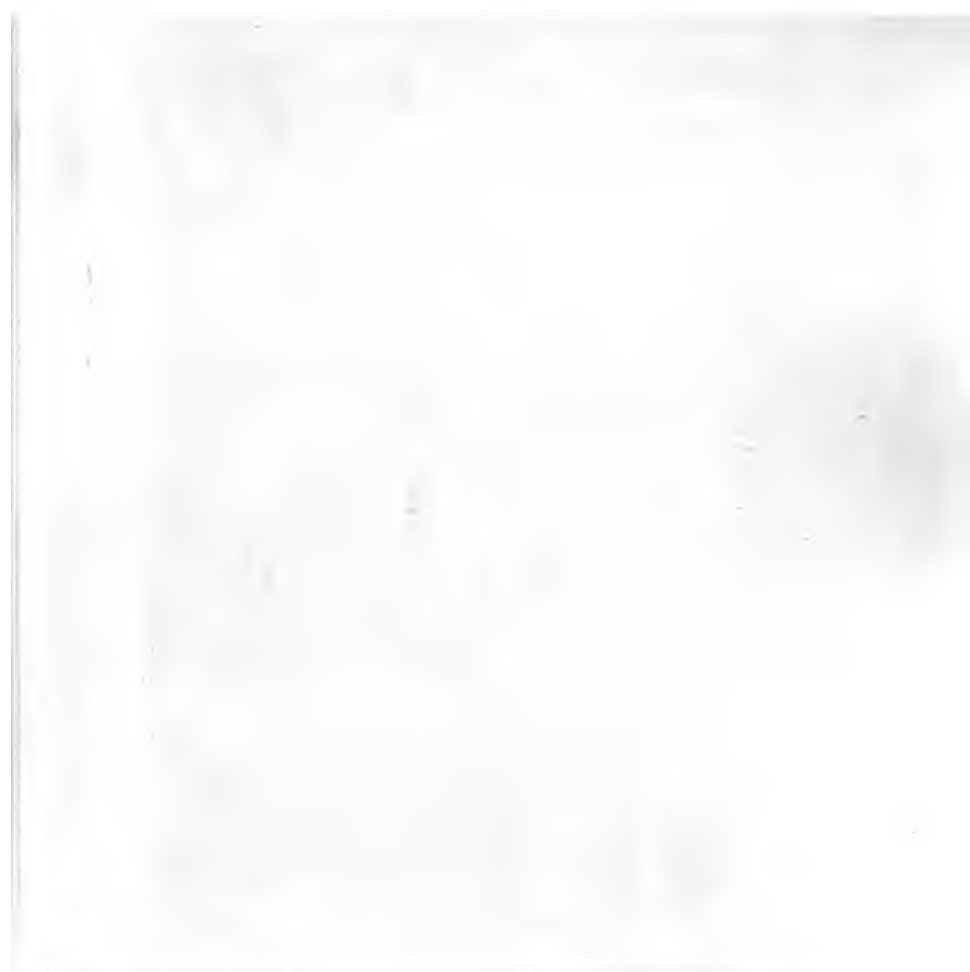
A. EARTHQUAKE DAMAGE DUE TO LACK OF TIE AND BRACING, GEOLOGICAL DEPARTMENT, LELAND STANFORD JUNIOR UNIVERSITY.

Photograph by Richard L. Humphrey.



B. EARTHQUAKE EFFECT ON ARCHES LELAND STANFORD JUNIOR UNIVERSITY.

Spalling of caps and movement of upper part of columns. Photograph by Richard L. Humphrey.





.I. ENDURANCE OF WALLS TIED TOGETHER WITH STEEL RODS, LEE BROTHERS' WAREHOUSE, SANTA ROSA.

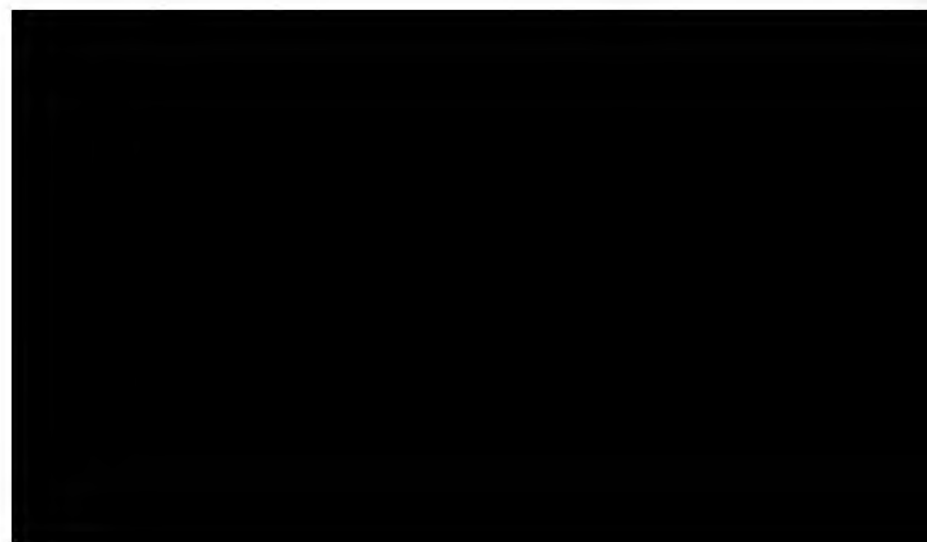
Slightly damaged at cornice. The few blocks which were thrown down by the earthquake were replaced previous to the taking of the photograph.



II. WALL THROWN DOWN BY EARTHQUAKE VIBRATIONS OF ROOF TRUSSES WHICH WERE NOT TIED TO WALL, VANDERVOORT BROTHERS' LIVERY, PALO ALTO.

EARTHQUAKE EFFECTS ON CEMENT-BLOCK WALLS.

Photographs by Richard L. Humphrey.





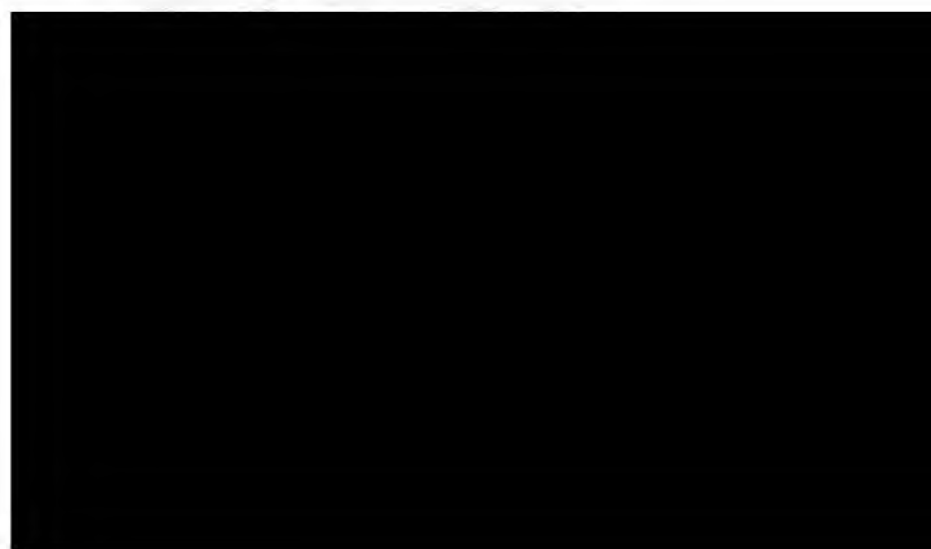
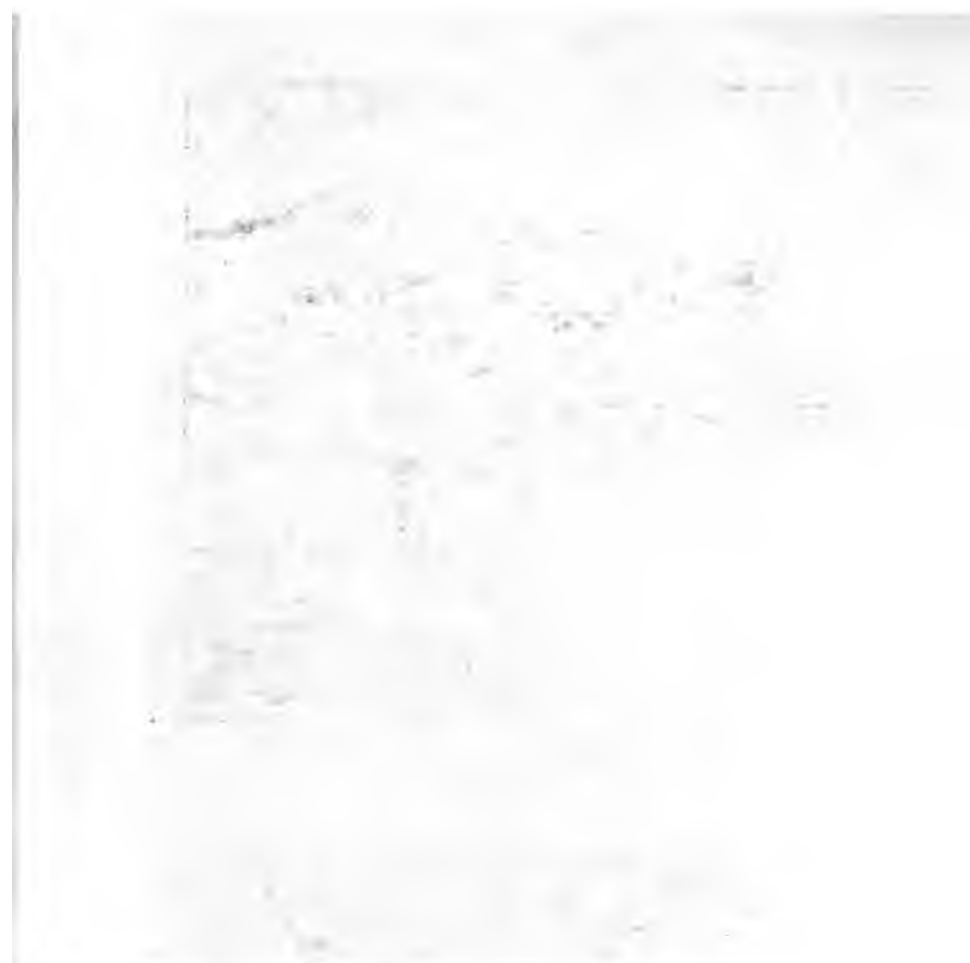
1. LOOSENING OF ARCH STONES AND SPALLING OF COLUMNS BY EARTH-
QUAKE FRANCIS SCOTT KEY MONUMENT, GOLDEN GATE PARK, SAN
FRANCISCO.

Photograph by Richard L. Humphrey



2. UNDAMAGED REINFORCED-CONCRETE STRUCTURE AT MILLS COLLEGE,
NEAR OAKLAND.

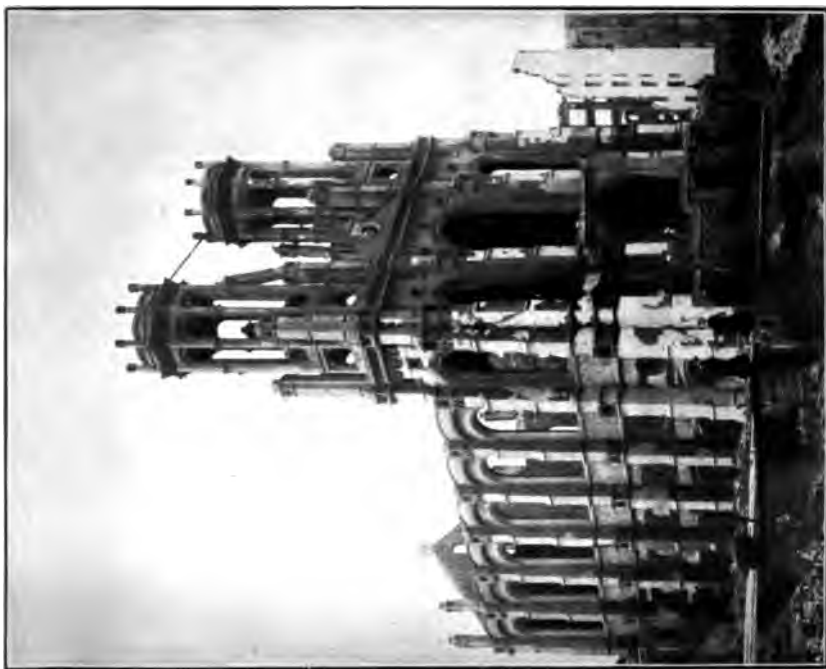
Ball tower, within a few feet of a brick building that was badly racked by the earthquake.
Photograph by Richard L. Humphrey





A. RACKING OF NEWLY CONSTRUCTED BUILDING, SYNAGOGUE, GEARY AND FILLMORE STREETS, SAN FRANCISCO.

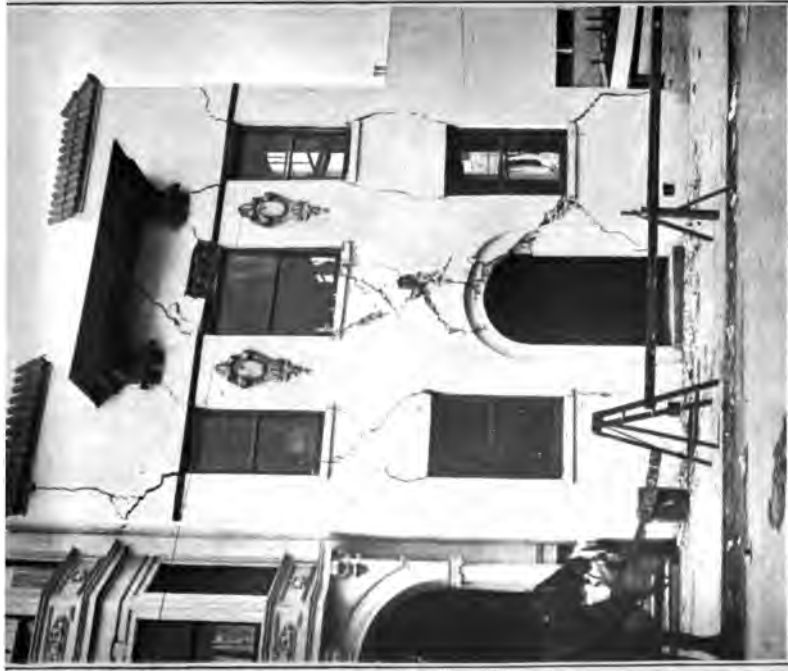
Note the separation of the brick veneer from the backbone, also the racking of the wall at



B. GOOD EARTHQUAKE ENDURANCE OF BUTTRESSED WALLS, SYNAGOGUE EMANUEL, SAN FRANCISCO.

Photographs submitted by Richard I. Humeau





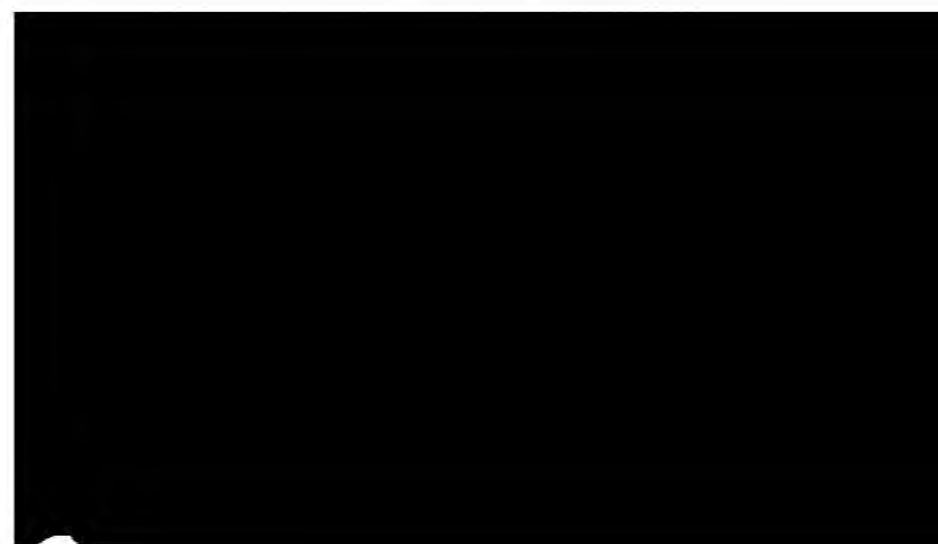
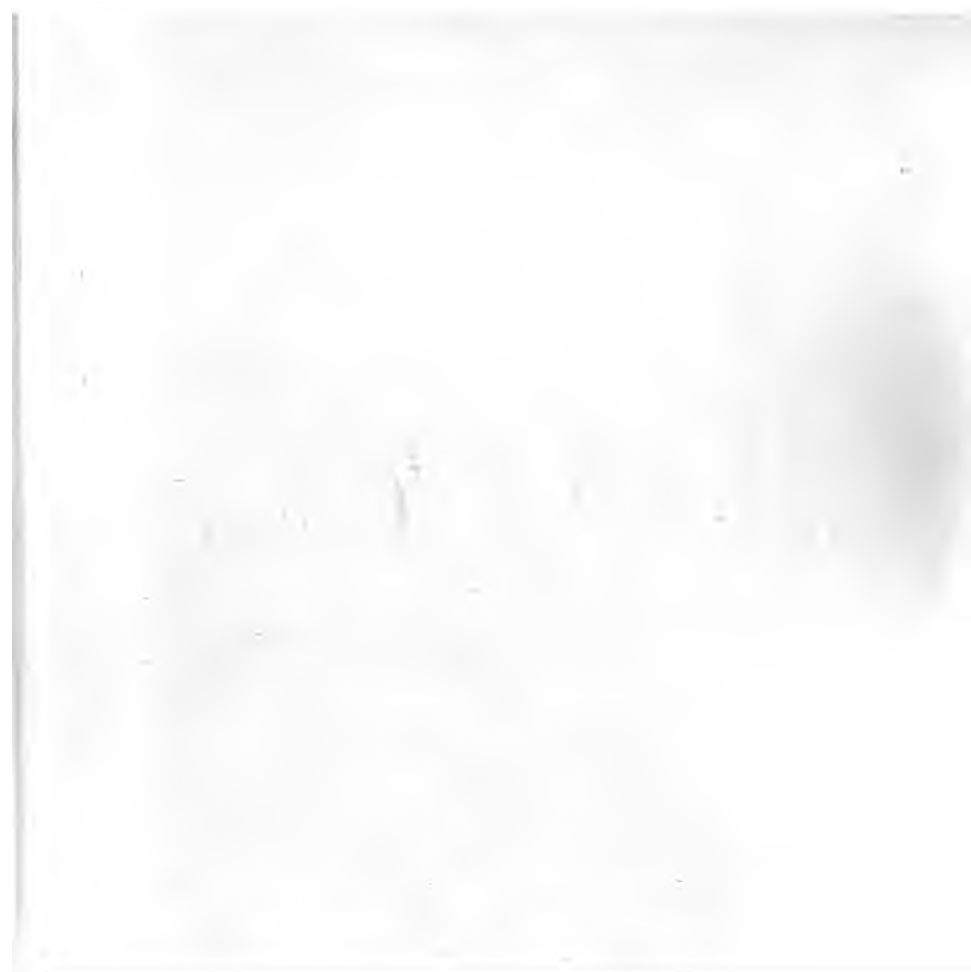
.1. X CRACKS IN BRICKWORK, CAUSED BY ROCKING, HOUSE IN SAN FRANCISCO.

Photograph submitted by Richard L. Humphrey.



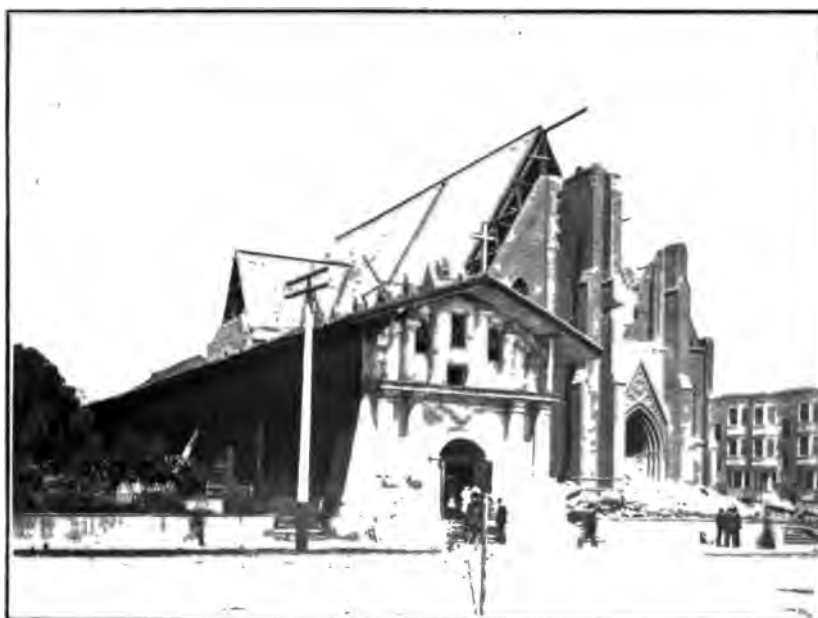
.2. SLIP OF FOUNDATION OF CYCLORAMA, STRAWBERRY HILL, GOLDEN GATE PARK, SAN FRANCISCO, CAUSING COLLAPSE OF THE STRUCTURE.

Photograph by Richard L. Humphrey.



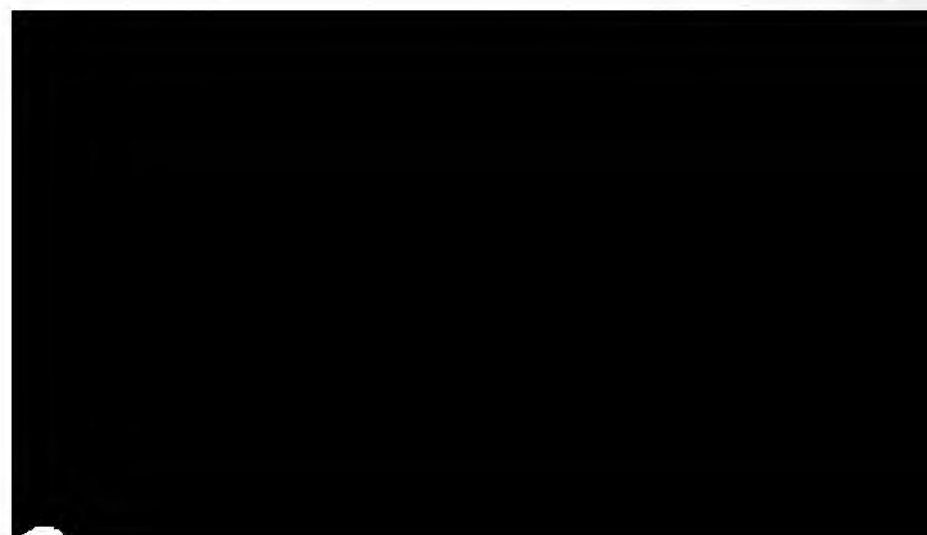


1. EARTHQUAKE EFFECT ON STRUCTURE OF REINFORCED CONCRETE OF POOR QUALITY.
Cyclorama, Strawberry Hill, Golden Gate Park, San Francisco. Photograph by Richard L. Humphrey.



2. EFFECT OF EARTHQUAKE ON ADJACENT BUILDINGS OF DIFFERENT TYPE AND CONSTRUCTION

Old Mission Dolores, San Francisco, undamaged. Tower of new church adjoining was so badly damaged that it had to be taken down. Photograph by Richard L. Humphrey.





1. FAILURE OF CAST-IRON SHELL OF CONCRETE-FILLED CAST-IRON COLUMN BY FIRE, ACADEMY OF SCIENCES BUILDING, SAN FRANCISCO. The concrete core supports the load. Note also the effect of the earthquake on the brick wall in the rear. Photograph by Richard L. Humphrey.



2. SPALLED GRANITE, MARKET STREET ENTRANCE OF AETNA BUILDING, SAN FRANCISCO.

Photograph by Richard L. Humphrey.



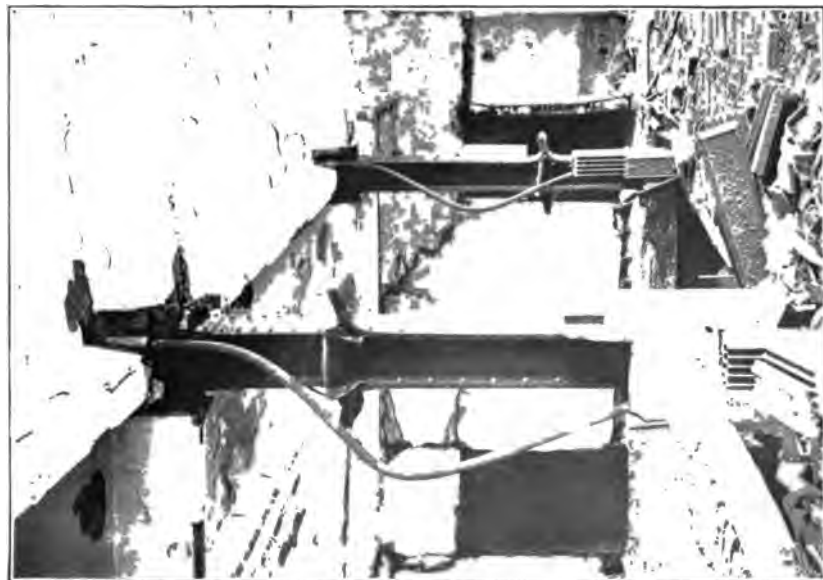
1. SUBSIDENCE OF STREET IN FRONT OF ÆTNA BUILDING. SAN FRANCISCO.

Photograph by John Stephen Sewell.



**2. FIRE ENDURANCE OF CONCRETE, ANNEX OF ACADEMY OF SCIENCES BUILDING
SAN FRANCISCO**

**Reinforced-concrete floors and concrete-filled cast-iron columns with plaster covering. Photograph by
Richard L. Humphrey.**



1. BUCKLEY COLUMNS AND COLLAPSED FLOOR PANEL,
REEDY & JONES BUILDING, SAN FRANCISCO.



2. INCIPENT FAILURE OF NAKED CAST-IRON COLUMN IN CITY
HALL, SAN FRANCISCO.

Position as seen moment of failure. Photograph by John Steinhilber, Cassell.





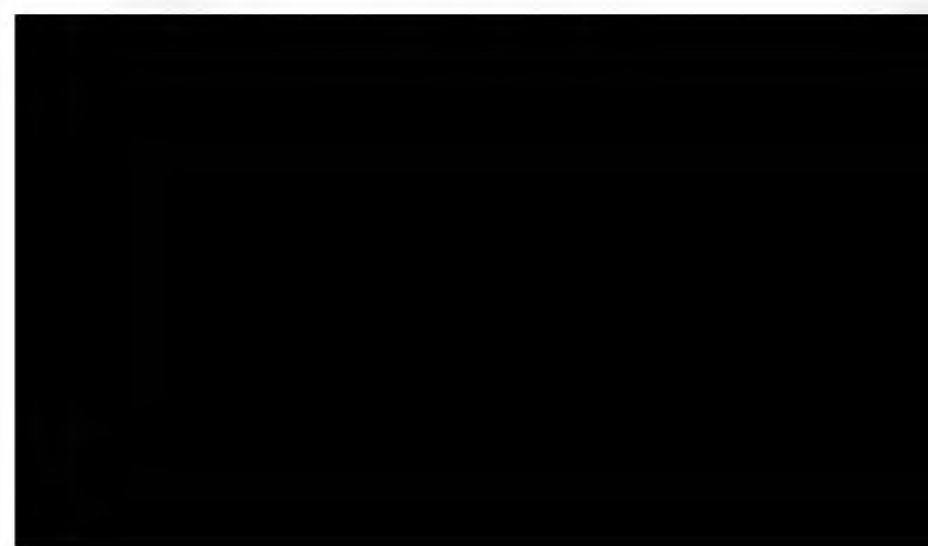
1. EARTHQUAKE ENDURANCE OF REENFORCED-CONCRETE BUILDING, BEKINS VAN AND STORAGE COMPANY'S WAREHOUSE, SAN FRANCISCO, UNDER CONSTRUCTION.

The only building of pure reenforced-concrete type in the city. The brick walls composing the shell of the building were cracked, but the reenforced-concrete floors and columns were uninjured. Photograph by Richard L. Humphrey.



2. FAILURE OF TERRA-COTTA COLUMN COVERINGS RESULTING IN BUCKLED COLUMNS, ENDURANCE OF CINDER-CONCRETE FLOORS; CENTER OF GROUND FLOOR, ARONSON BUILDING, SAN FRANCISCO.

Photograph by Richard L. Humphrey.





A. EARTHQUAKE ENDURANCE OF A WELL-CONSTRUCTED BRICK BUILDING: APPRAISERS' WAREHOUSE, SAN FRANCISCO.

The walls were built with full-header courses and show only a few slight cracks, although the building was located on alluvial soil. Photograph by Richard L. Humphrey.



B. FAILURE OF ORNAMENTAL TERRA COTTA, CROCKER ESTATE BUILDING, SAN FRANCISCO.

This terra cotta failed, though solidly filled with brick mortar. The damage shown was probably due to fire, although damage of this kind was caused by both earthquake and fire. Photograph by John Stephen Sewell.





1. EARTHQUAKE CRACKS IN WALL OF VAULT, CALIFORNIA CASKET COMPANY'S BUILDING, SAN FRANCISCO.

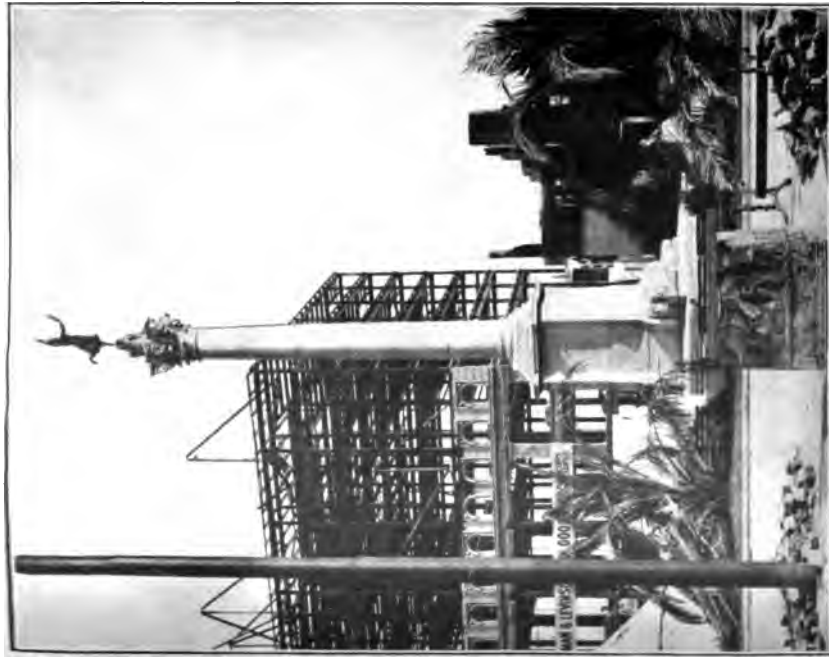
Photograph by Richard L. Humphrey.



2. COLLAPSE OF FLOOR PANEL CAUSED BY LOAD FALLING FROM A FLOOR ABOVE, THIRD FLOOR OF ÆTNA BUILDING, SAN FRANCISCO.

The failure of the upper floor was due to the softening by loss of reinforcing steel bars. Photographs by Richard L. Humphrey.





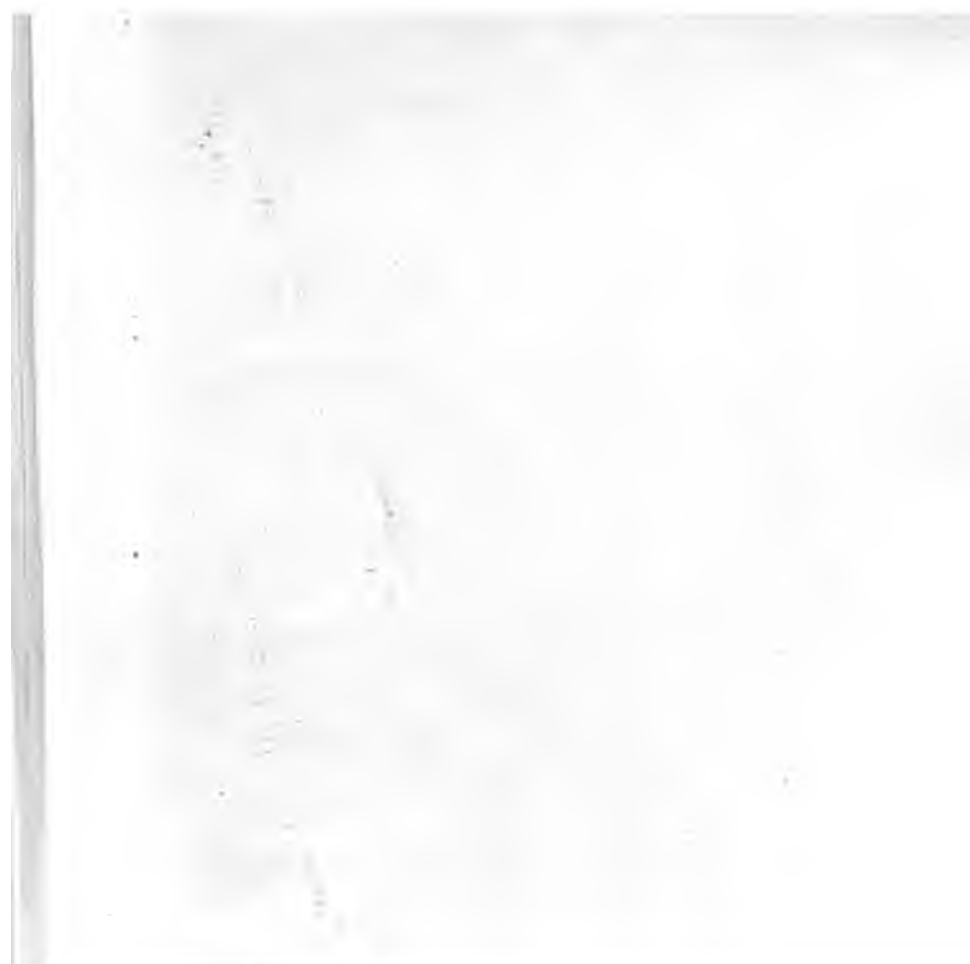
.J EARTHQUAKE DAMAGE MINIMIZED BY SPECIAL CONSTRUCTION, DEWEY MONUMENT, SAN FRANCISCO.

The drums on the right were displaced slightly, but were kept from falling by a steel



.B. X CRACKS IN WALLS, DUE TO ROCKING OF BUILDING BY EARTHQUAKE, CHRONICLE BUILDING AND ANNEX, SAN FRANCISCO, LOOKING EAST.

The Palace Hotel (at the right) was completely gutted by fire, but the walls remained

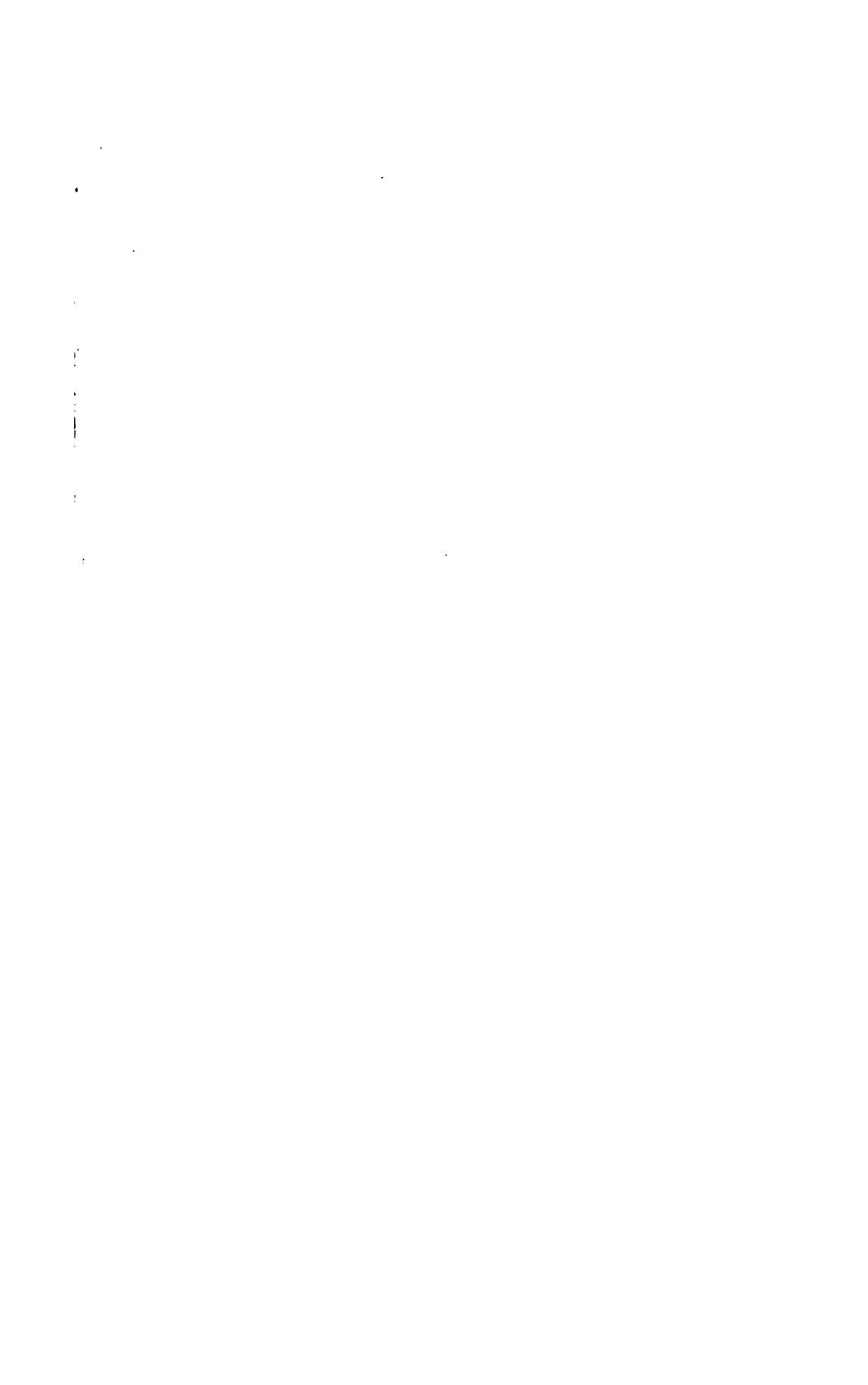




RUIN OF THE \$7,000,000 CITY HALL, SAN FRANCISCO, BY EARTHQUAKE AND FIRE.

Photograph

ulé.





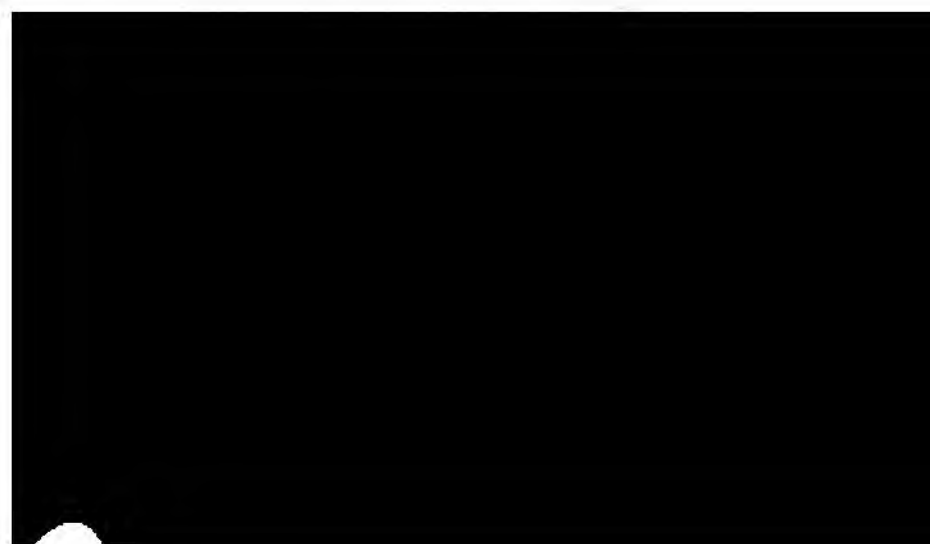
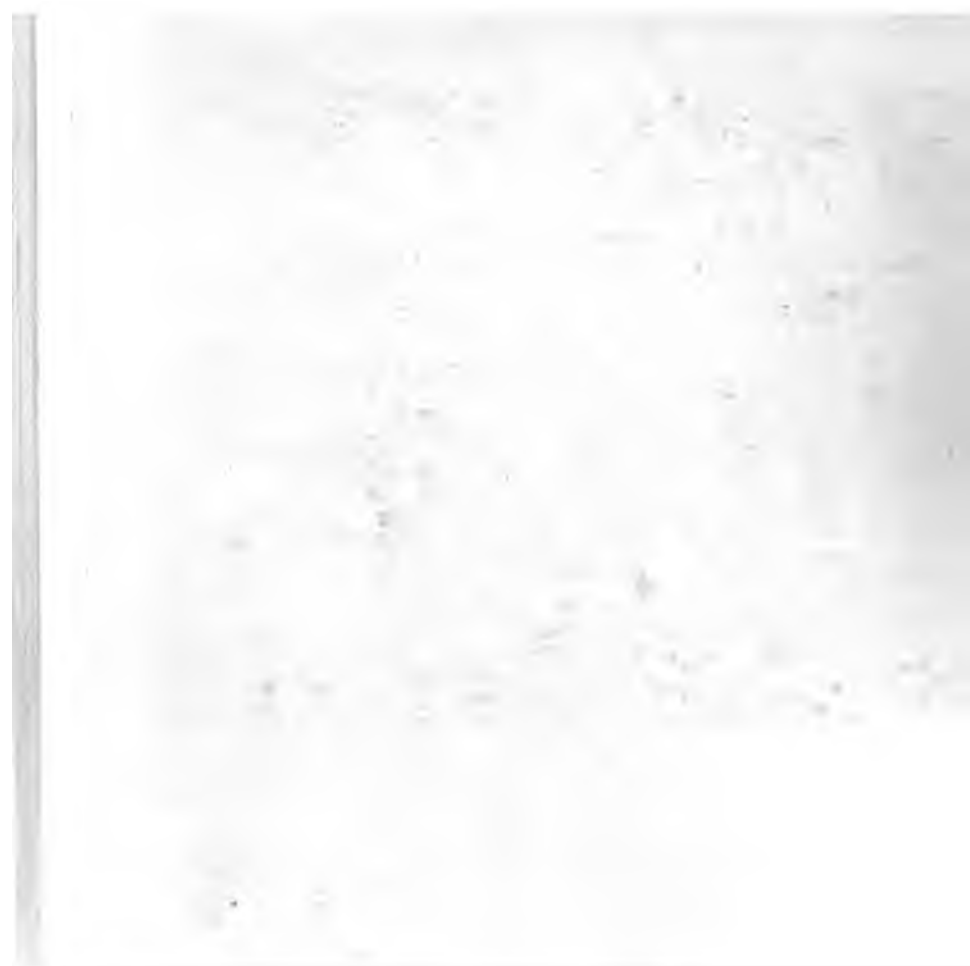
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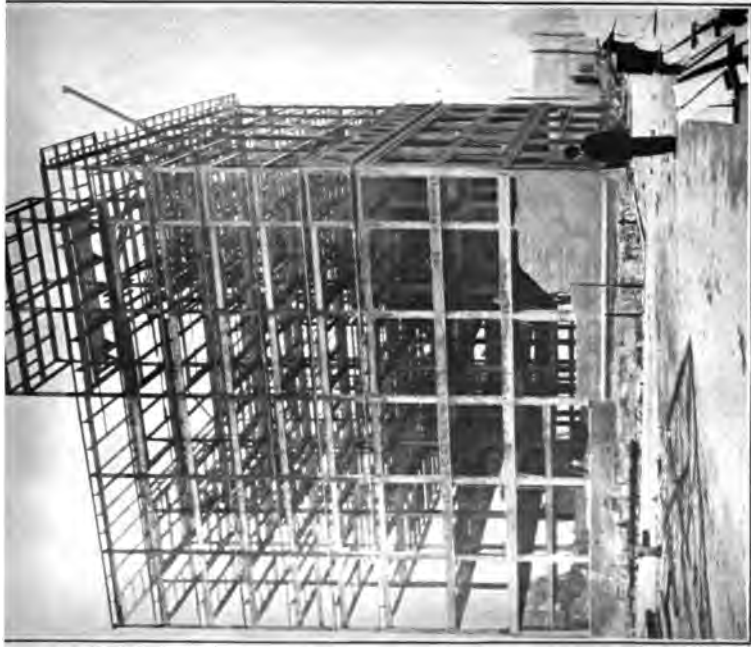


B

**COMPLETE FAILURE OF SLOW-BURNING WOOD CONSTRUCTION,
THE EMPORIUM, SAN FRANCISCO.**

large department store. A, Interior (photograph by John Stephen Sewell); B, Exterior (photograph by Richard L. Humphrey).





A. BEHAVIOR OF STEEL FRAME, BUTLER BUILDING (INCOMPLETE), AT THE SOUTHWEST CORNER OF GEARY AND STOCKTON STREETS, SAN FRANCISCO.

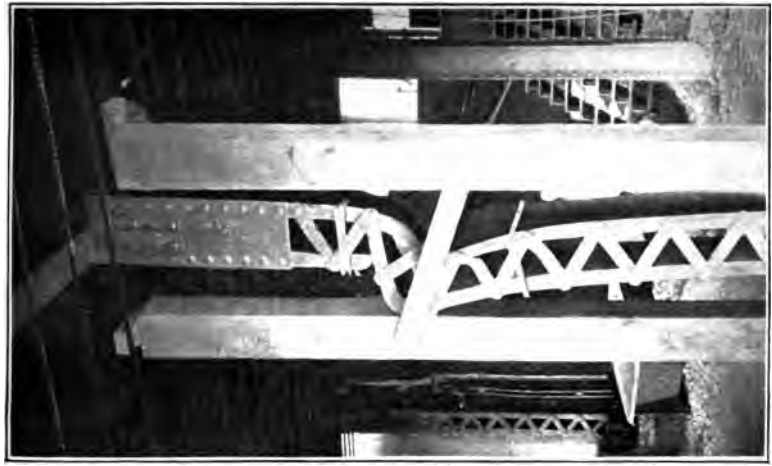
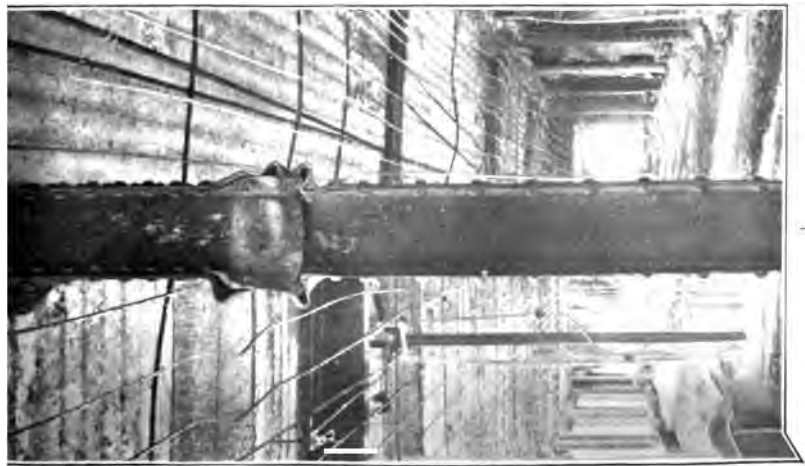
Walls taken down in places because of earthquake damage, although damage to steel by earthquake and fire was nominal. Photograph by John Stephen Sewell.



B. EARTHQUAKE DAMAGE TO STONE PIERS, JAMES FLOOD BUILDING, SAN FRANCISCO.

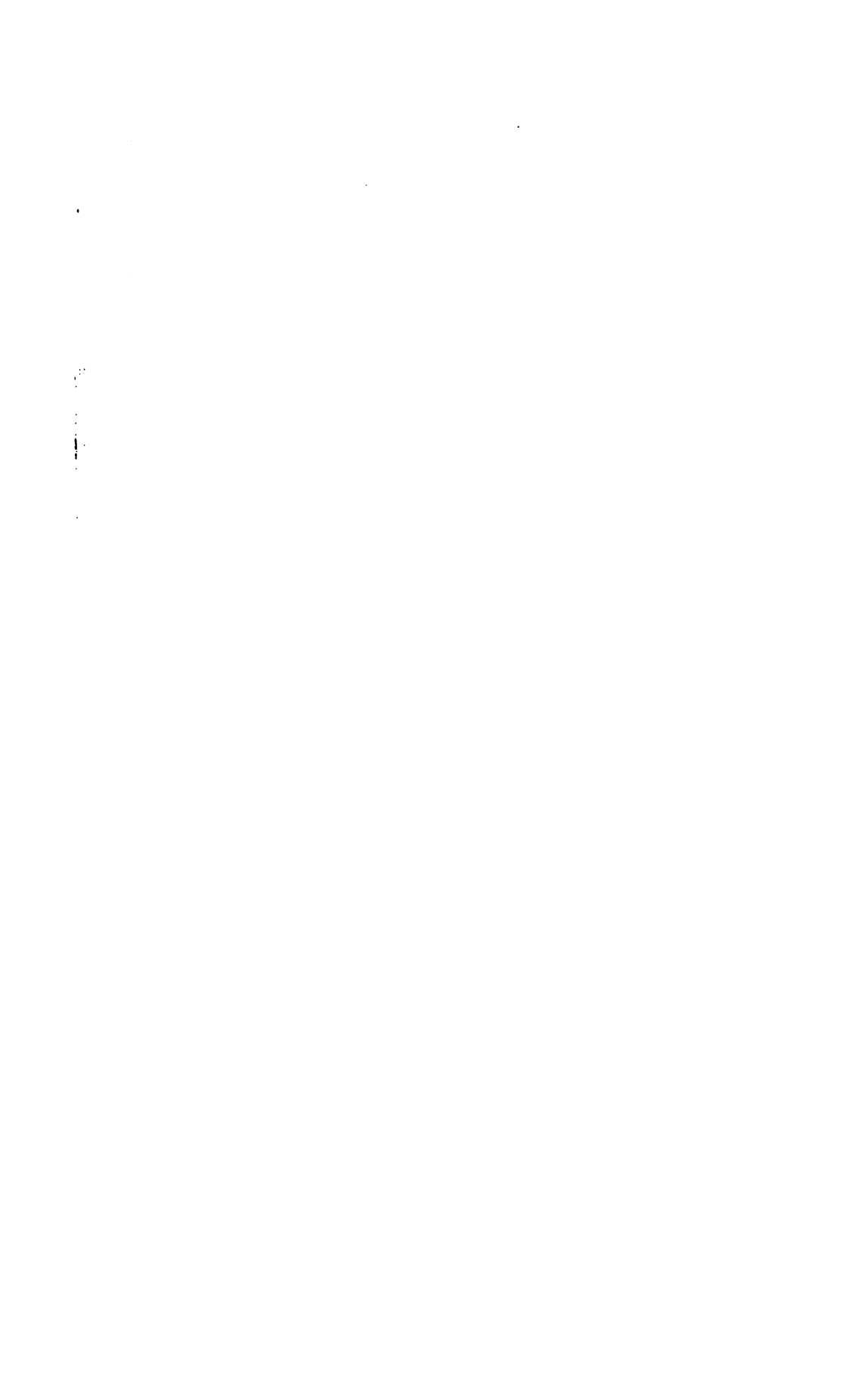
Photograph by John Stephen Sewell.





BUCKLING OF COLUMNS DUE TO FAILURE OF PLASTERED METAL-LATH FIREPROOFING, FAIRMOUNT HOTEL, SAN FRANCISCO.

The method of fireproofing was to incase the column between the metal lath forming the partitions. Photographs by Richard L. Humphrey.





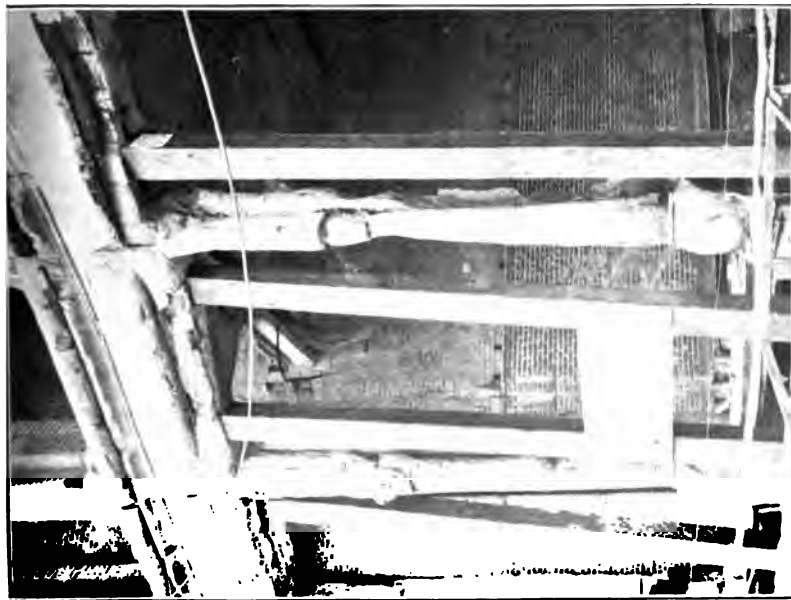
A. INCIPIENT BUCKLING OF COLUMNS FROM HEAT, FIRST STORY, JAMES FLOOD BUILDING, SAN FRANCISCO.

The brick filling probably saved the columns from fatal buckling or collapse. Photograph by John Stephen Sewell.



B. FAILURE OF SUSPENDED CEILING, HALL OF JUSTICE, SAN FRANCISCO.

Photograph by Richard L. Humphrey.



11. GRANITE COLUMN SPALLED BY FIRE. HOBART BUILDING, SAN FRANCISCO.

Photograph by Richard L. Humphrey



12. BUCKLING OF COLUMNS DUE TO FAILURE OF WIRE-MESH-AND-PLASTER FIREPROOFING. HOTEL HAMILTON, SAN FRANCISCO.

The fireproofing on either side shows the general condition in which it was left by the fire. It was stripped away from the column just before the photograph was taken in order to show the buckling. Photograph by A. L. A. Himmelwright.





A. STONEWORK SPALLED BY FIRE, HIBERNIA SAVINGS AND LOAN SOCIETY'S BUILDING, SAN FRANCISCO.

Photograph by Richard L. Humphrey.



B. EARTHQUAKE DAMAGE, JACKSON BREWING COMPANY'S BUILDING, SAN FRANCISCO.

Light walls, badly bonded and laid up with poor lime mortar, and flimsily constructed steel work. Photograph by Richard L. Humphrey.



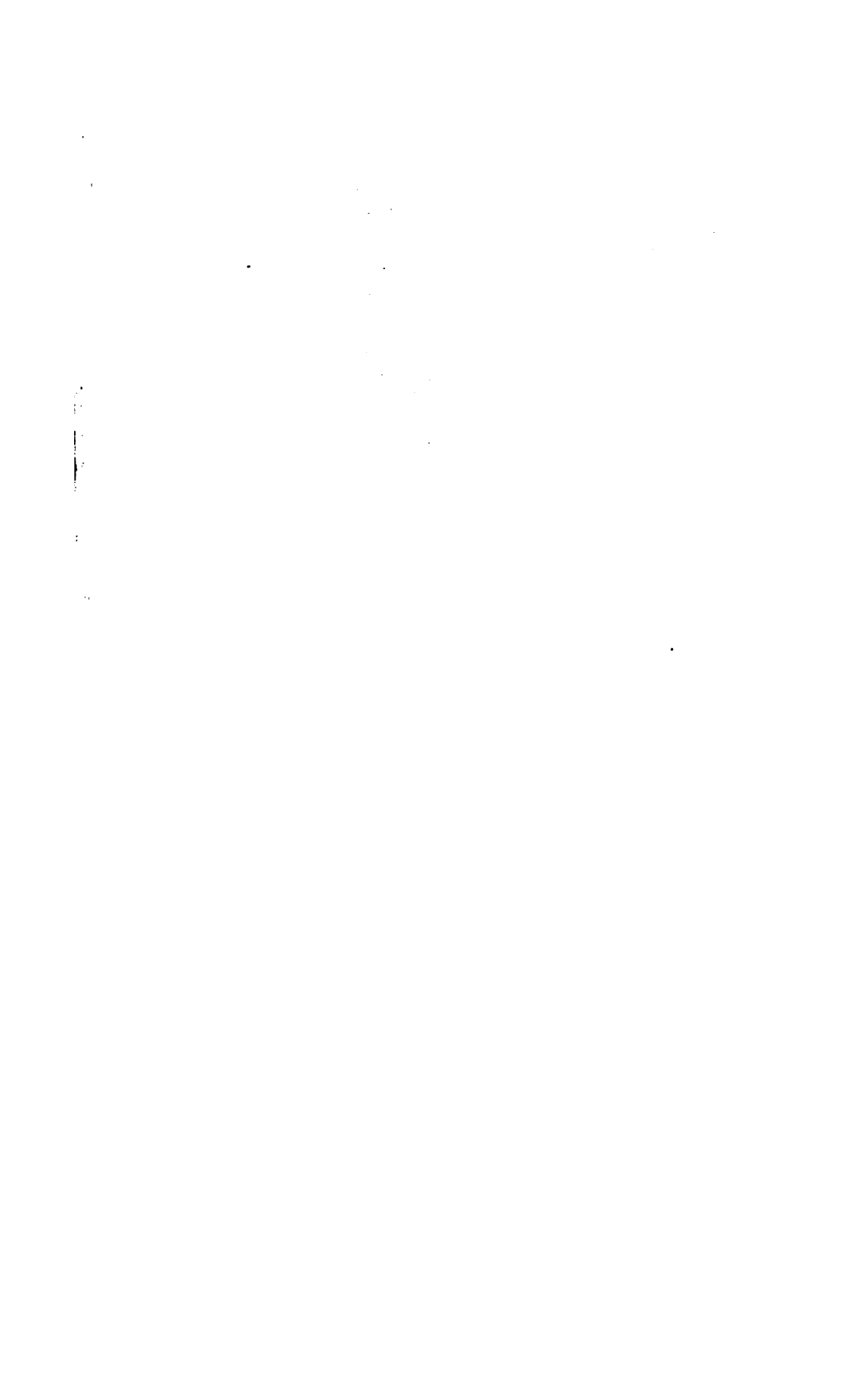
GOOD EARTHQUAKE ENDURANCE OF A BUILDING OF THE MONUMENTAL TYPE: UNITED STATES MINT, SAN FRANCISCO.

wing only slight damage to brick stack, probably due to earthquake. Photograph by John Stephen Sewell.



SPALLING OF STONWORK BY FIRE NORTHWEST FRONT OF UNITED STATES MINT.

Photograph by Richard L. Humphrey





A. WRECKED TOWER AND SPALLED STONEWORK, HALL OF JUSTICE, SAN FRANCISCO.

Photograph by John Stephen Sewell.



B. COMPLETE WRECK BY EARTHQUAKE, DUE TO POOR DESIGN, MAJESTIC THEATER, SAN FRANCISCO.

Photograph by Richard L. Humphrey.



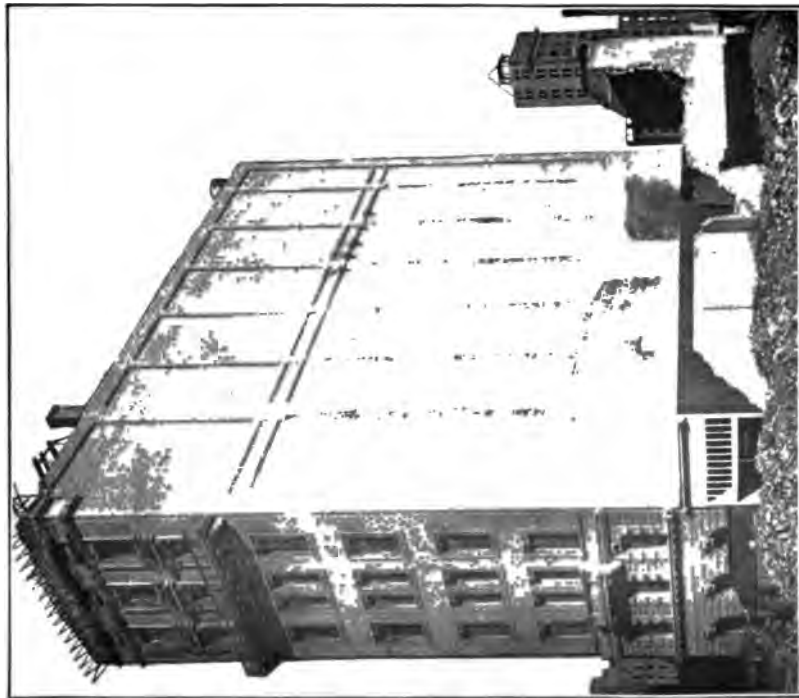
A. SPALLING OF ENAMELED BRICK IN LIGHT WELL, AND FAILURE OF FIREPROOFING OF WINDOW-FRAME SEPARATORS, MERCHANTS' EXCHANGE BUILDING, SAN FRANCISCO.

Photograph by Richard L. Humphrey.



B. BUCKLING OF BASEMENT COLUMN DUE TO FAILURE OF TERRA-COTTA COVERING IN FIRE, MILLS BUILDING, SAN FRANCISCO.

Photograph by Richard L. Humphrey.



1. WESTERN UNION BUILDING, SAN FRANCISCO, CALIF. BUILDING SUBJECTED TO SEVERE HEAT DURING EXCAVATION FOR PAUL & STATES TELEPHONE AND TELEGRAPH COMPANY, SAN FRANCISCO.
Rolling shutters with support of brick walls, concrete floors and concrete protection for columns and girders. Photograph by Richard L. Humphrey.



2. WARPING OF PLASTERED METAL-LATH COVERING BY FIRE, MURPHY BUILDING, SAN FRANCISCO.
Photograph by Richard L. Humphrey.



A. ROOF TRUSSES DAMAGED BY HEAT THROUGH FAILURE OF TERRA-COTTA COVERING, MUTUAL LIFE BUILDING, SAN FRANCISCO.

Photograph by Richard L. Humphrey.



B. EFFECT OF SETTLING OF GROUND SUBJECT TO EARTHQUAKE VIBRATIONS STEEL-FRAME BUILDING UNDER CONSTRUCTION.

The concrete basement walls were not reinforced. Post-office in the background. Photograph by Richard L. Humphrey.



.I. CRACKS IN MASONRY, PAVILION OF POST-OFFICE, SAN FRANCISCO.

The window reveal and sill were jostled together by the earthquake at the point indicated by the arrow. Photograph by John Stephen Sewell.



.II. EFFECT OF SLIP, MISSION STREET, SAN FRANCISCO.

Corner of post-office building at the left. Photograph submitted by Richard L. Humphrey.



A. CRACKS IN MASONRY AND SETTLING OF OUTER TERRACE, POST-OFFICE BUILDING, SAN FRANCISCO.

The surface of the street went down at this point at least 4 feet. Photograph by John Stephen Sewell.



B. EFFECT OF EARTHQUAKE IN LOOSENING STONEMWORK, NORTHEAST FACE OF POST-OFFICE BUILDING.

Photograph by Richard L. Humphrey.



A



B

FAILURE OF HOLLOW TERRA-COTTA TILE FIREPROOFING.

A, First story of Spring Valley Water Company's Building, San Francisco (photograph by John Stephen Sewell);
B, Mills Building, San Francisco (photograph by Richard L. Humphrey). The lower webs of the floor tiles
were spalled or taken entirely off by the fire.



**A. BRICKWORK THROWN DOWN BY EARTHQUAKE VIBRATION,
TOWER OF UNION FERRY BUILDING, SAN FRANCISCO.**

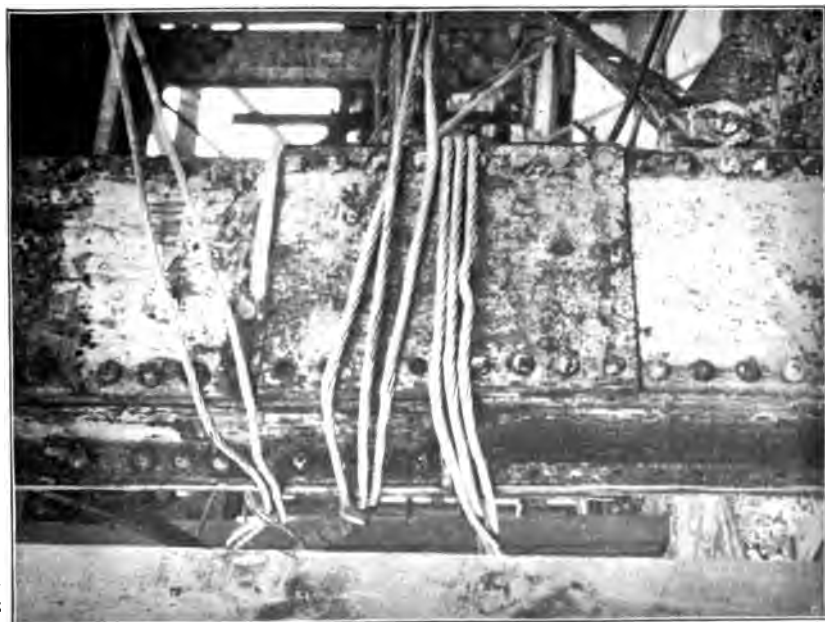
Note bending of time-ball shaft. Photograph submitted by Richard L. Humphrey.



**B. EFFECT OF SEVERE SHAKING ON WELL-BONDED BRICKWORK FILLED WITH GOOD
MORTAR, TOWER OF UNION FERRY BUILDING.**

Note *sagged* tie-rod, stretched by the racking of the structure. Photograph by John Stephen Sewell.





A



B

SHEARED RIVETS, TOWER OF UNION FERRY BUILDING, SAN FRANCISCO.

A In column cover plate. B In diagonal connection. Photographs by Richard I. Hurnshaw



A. BUCKLING OF BASEMENT COLUMN DUE TO FAILURE OF PLASTERED-METAL-LATH FIREPROOFING, RIALTO BUILDING, SAN FRANCISCO.

Photograph by Richard L. Humphrey.



B. DAMAGE SAID TO HAVE BEEN CAUSED BY DYNAMITE, RIALTO BUILDING.

Photograph by John Stephen Sewell.





A. COLLAPSE OF BUILDING DUE TO BUCKLING OF COLUMNS, SPRING VALLEY WATER COMPANY'S BUILDING, SAN FRANCISCO.

Photograph by Richard L. Humphrey.



B. FAILURE OF TERRA-COTTA TILE COVERING IN FIRE, UNION TRUST COMPANY'S BUILDING, SAN FRANCISCO.

Photograph by Richard L. Humphrey.



A. AN UNFINISHED STEEL SKELETON, WITH NONFIREPROOFED STEEL WORK.



B. UNPROTECTED STEEL FRAME AND GENERAL FLIMSY CONSTRUCTION COWELL BUILDING.

EFFECTS OF HEAT ON STEEL WORK, SAN FRANCISCO.

Photographs by Richard L. Humphrey.



A. ENDURANCE OF BRICK VAULT.

This vault, which was in the original Wells-Fargo Building, San Francisco, passed the fire test satisfactorily, although the building was completely destroyed. Note the defective steel "fireproof" safes near by. Photograph by Richard L. Humphrey.



B. ABSOLUTE FAILURE OF SO-CALLED "FIREPROOF" SAFES

In the rear are the Palace Hotel (at the left) and the Crocker Building (at the right). Photograph by Richard L. Humphrey



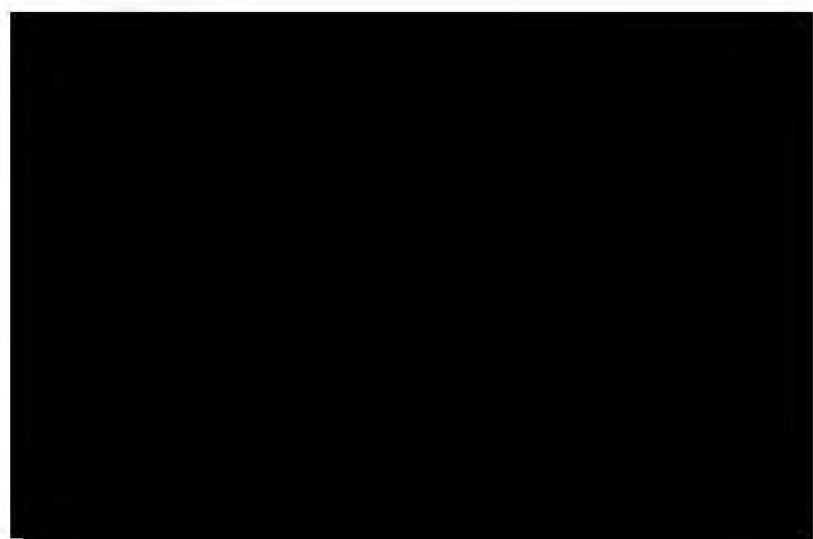
A. EARTHQUAKE DAMAGE TO BRICK STACK OF STAR SECTION, VALENCIA STREET POWER STATION, SAN FRANCISCO.

Showing peculiar crack in reentrant angle. Photograph by Richard L. Humphrey.



B. GENERAL EARTHQUAKE EFFECT ON FRAME BUILDINGS SITUATED ON ALLUVIAL SOIL, HOWARD STREET, SAN FRANCISCO.

Photograph by A. C. Lawson





DESTRUCTION BY FIRE, SAN FRANCISCO.

View of Russian Hill, showing unburned houses on summit of Russian Hill. St. Francis Roman Catholic Church, with its excellent brick walls, in the foreground. Photograph submitted by Frank Soule.

